# ELECTRICITY CONTROL:

## A Treatise

ON

## ELECTRIC SWITCHGEAR AND SYSTEMS OF ELECTRIC TRANSMISSION.

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# PREFACE.

Electrical engineers have such an enormous library from which to select their technical literature that to increase its dimensions must be considered an offence, unless it can be shown that there is room for a new book on any particular subject. My excuse for so trespassing must be that, although many books exist on boilers, engines, electric generators, mains, transformers, lamps, etc., no one has dealt exclusively with that part of the system that has been rightly termed the 'nerve centre.'

A reason for this apparent neglect of a very important section is to be found in the fact that such rapid advances in switchgear design are daily being made that it is almost impossible for a book, which necessarily is some months in passing through the press, to be absolutely up-to-date.

It should be explained at the outset that the present work does not pretend to be purely a record of the best modern practice in switchgear design. Quite a large proportion of it is devoted to descriptions of various kinds of apparatus that have been abandoned, with, in many cases, a brief explanation of the reasons of failure.

Some engineers claim that their time is too valuable to waste in endeavouring to understand failures, and they are quite content to be guided in the preparation of their schemes by the dictates of fashion. But to the engineer who, when he meets a difficulty, is not satisfied until he has got to the bottom of it—to the designer who will often make efficient use of a device that has failed by applying it to another purpose, and to the student who conscientiously wishes to prepare to deal with the difficulties he may meet with in his after career—the brief records given of difficulties that have been encountered in the evolution of modern switchgear will, I trust, prove of some assistance.

There are certain classes of switchgear that I have not attempted to deal with, such as small installation switches, motor controllers, and automatic pressure regulating devices, all of which might have come within the scope of the work; but the subject as a whole is such an inexhaustible one that I have thought it best to confine my attention to

the control of that portion of the system between the generators and the distributing centre.

I wish to take this opportunity of thanking the many friends who have assisted me in this work, particularly the engineers and manufacturers who have lent me drawings and blocks and furnished me with full information respecting their designs.

My thanks are especially due to my friends, Mr A. H. Foyster and Mr C. S. Thomson, for the great assistance they have given me in correcting the proofs, and to my late assistant, Mr C. Hanna, by whom over 150 of the line drawings and diagrams with which the book is illustrated were drawn. The majority of these were specially designed with a view to showing as simply and clearly as possible in one illustration those features of the apparatus to which it was desired to draw attention. I must also acknowledge the help of another old assistant, Mr C. Coleman, who, in the small hours of many a night during the past ten years, has assisted me in carrying out the various experiments referred to.

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CROMWELL CHAMBERS,
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## CHAPTER I.

### GENERAL PRINCIPLES OF SWITCHGEAR DESIGN.

Introductory remarks—The great importance of simplicity—Advantage of single-pole switchgear for earthed systems—Fire risks to be guarded against—Necessity of non-combustible construction—Fires liable to be started by :—excessive arcing, insufficient area of conductors, the scattering of molten metal, bad contacts, or the failure of insulation—Precautions against accidents to attendants—Notes *re* earthing—The advantages and disadvantages of earthing cases of instruments, etc. —Duplication of 'bus bars and fuses sometimes useful, if not allowed to involve complication—Importance of accessibility and standardisation—The advantages and disadvantages of compact and scattered switchgear—American views on this subject—Capital outlay on switchgear should be considered, particularly for small installations—The best position for switchboard, whether this should be in the engine-room or in a separate switch-room.

**Introductory Remarks.**—Any electrical engineer who has visited many of the electricity generating stations in this country and abroad must have remarked how widely different in design and general arrangement are the switchgears controlling the generators and circuits in the respective stations. This lack of standardisation is probably to a great extent unavoidable. It may be attributed to the fact that the conditions to be dealt with are generally peculiar to each individual case. There are, however, certain universally recognised general principles which are applicable to all arrangements. These are so well known that it appears almost unnecessary to refer to them, added to which, they have been admirably dealt with by Mr Wordingham in his book on *Central Electrical Stations.* It is felt, however, that a treatise on Electrical Switchgear would not be complete without a brief record of some of these general principles. Therefore a small space will be devoted to this purpose.

**Simplicity.**—All engineers will, without doubt, agree that, if there is one general principle to be insisted upon more than any other in preparing a scheme of electricity control, it is the absolute necessity of *simplicity.* All apparatu· not absolutely necessary should be avoided, and all screwed,

clamped, or other mechanical connections should be reduced to a minimum. The arrangement of the apparatus should be as diagrammatic as possible, so that a stranger to the board can see at a glance the object of each switch or instrument.

It must be admitted that in some of the early designs of switchgear this principle was not sufficiently recognised, and consequently many troubles arose which could have been entirely avoided but for the complexity of the switchgear and its connections.

The most important reformation that has ever been made in this direction was probably the first single-pole Ferranti board put in for the Portsmouth Corporation in 1894; and the universal popularity of this type of switchboard is undoubtedly in a great measure due to the continued observance of this important feature by its designers.

Prior to the installation of the Portsmouth board it was the generally recognised practice of all designers to provide switches and fuses on both poles, and the departure from this practice was viewed with a considerable amount of scepticism. Mr Ferranti, however, showed that where concentric feeders are used in connection with alternating current systems, it is quite unnecessary to provide means for disconnecting the terminal of a generator coupled to the outer conductor. The outer conductor should, however, be permanently connected to an earth-plate at the generating station.

It must not be supposed that the permanent earthing of the outer conductor is a necessity peculiar to systems where single-pole boards are used. It is, in fact, even more important to earth the outer where switches and fuses are inserted in the connections between both poles of the generator and the 'bus bars, as serious troubles are liable to arise through one of the connections to the outer bar being opened before the connection to the inner, unless the outer terminal of the generator partially disconnected is efficiently earthed. The cause of this trouble is indicated in fig. 1.

A and B are two generators connected in parallel to supply current to the 'bus bars C and D. E and G are the conductors of a concentric cable connected to these 'bus bars, E being the outer or earthed conductor. $F_1$, $F_2$, $F_3$, and $F_4$ are fuses inserted in each of the connections between the generators and the 'bus bars. So long as all the fuses referred to are intact the generators will be kept in step, and the maximum pressure between any two points will be the pressure across the 'bus bars. Should, however, the circuit become interrupted at, say, $F_1$, the generators will drop out of step; but, as they are connected on one pole, they will, when 180 degrees out of step, be in series with each other, and as a consequence there will be a difference of potential of double the working pressure across the point where the circuit has been interrupted. If the working pressure is, say, 2000 volts, the outer 'bus bar will be at earth potential, the inner 'bus bar 2000 volts above earth, and the terminal of the generator that has

been disconnected from the outer 'bus bar will be 2000 volts above the inner 'bus bar, and consequently 4000 volts above earth. This has frequently caused the armature at a point near the outer connection of the interrupted generator to flash to pole pieces. It will be evident that, if the outer terminals of each of the generators are permanently connected to earth, it

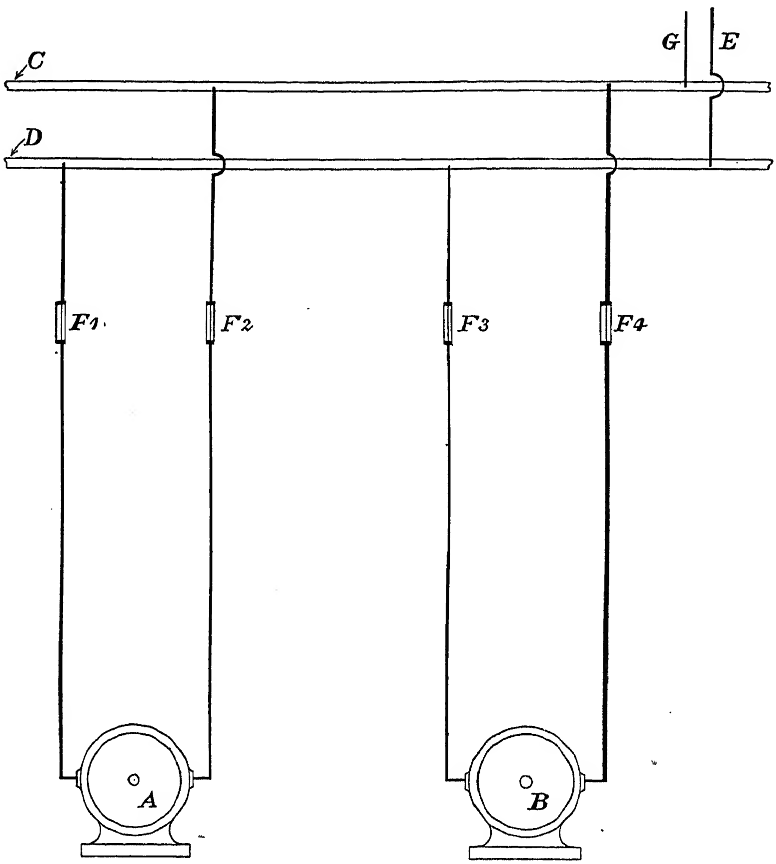


FIG. 1.—Diagram illustrating danger of fusing both poles of alternating current generator.

is not possible to get a difference of potential exceeding the working pressure of the generators at any point of the system from this cause.

**Fire Risks.**—Of almost equal importance to simplicity is the necessity of taking every precaution to guard against the slightest risk of fire. The switchboard, the gallery, and all its surroundings must be constructed of incombustible materials. The necessity for this precaution has during recent years been fully recognised by nearly all designers; but a few years

ago quite the contrary was the case. The very name of switchboard implies switches mounted on wooden panels. Polished teak was a material largely used at one time for this purpose. An attempt was made to make this non-inflammable by covering it, in the neighbourhood of the switches, with thick sheets of asbestos; but it was very soon found that the arc formed on breaking a moderately heavy high-tension current was of such a destructive nature that asbestos melted almost like butter under its influence.

Instruments and switches are now generally mounted on slate or marble panels, the panels being supported by an iron framework. In some cases the instruments, etc., are mounted directly on to the iron framework, but this arrangement does not generally look as neat as nicely polished slate or marble panels.

The danger of a fire being started on a switchboard arises, amongst other causes, from the following:—

(1) An arc may be drawn out in breaking a heavy current at high pressure. The various methods that have been adopted to prevent excessive arcing on interrupting a circuit are dealt with in Chapter III.

(2) The area of the conductors may be insufficient to carry the working current, and as a consequence the rise of temperature due to $C^2R$ losses may be sufficient to melt the solder in the connecting thimbles. This will sometimes lead to the circuit being opened at this point and a destructive arc being formed. If the connections consist of cables insulated with some highly inflammable material, the danger is, of course, considerably increased.

(3) The blowing of a fuse is liable to scatter molten metal in every direction; should any of this metal drop on wood or other inflammable material it may set it on fire.

(4) Excessive heating may be caused by bad contacts. To avoid trouble from this source, it is necessary to provide ample area of contact and a good rubbing pressure between the surfaces. The surfaces of the contacts should also be kept thoroughly cleaned.

(5) The failure of insulation. This may be due to insufficient thickness or specific insulating strength of the material used, or it may be due to surface leakage on account of the accumulation of dirt or moisture.

(6) The bunching together of a number of leading-in cables has on more than one occasion led to disastrous results. The leads to the switchboard from the generators and feeders should be carried through a tunnel supported on brackets, as shown in fig. 2. As a further precaution each lead should be enclosed in a fireproof duct, or the leads may be of the new fireproof insulation.

**Precautions against Accidents to Attendants.**—A third point to be considered in designing a switchboard is the protection of attendants

from dangerous shocks or injury from other causes. It must be remembered that in a large generating station breakdowns may occur of a sufficiently alarming nature to make the very best and steadiest of men liable to momentarily lose their heads, or a man may slip and catch at something to save himself from falling without stopping to consider whether the supporting object is liable to be charged to a dangerous potential or not. It is necessary, therefore, to provide for contingencies

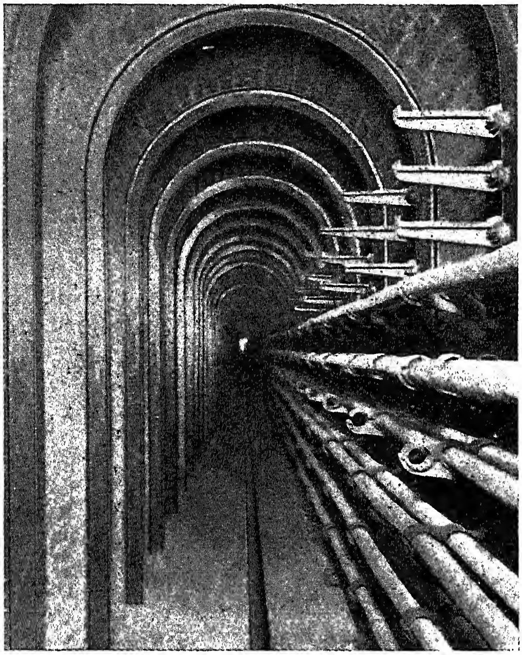

FIG. 2.—A cable subway.

of this sort, and the only efficient method of doing so appears to be to make it practically impossible for a man to touch any live high-tension connections.

Some switchboards have been erected with everything thoroughly protected in front of the board, but with numerous exposed connections at the back, and as it is at times necessary for an attendant to work behind the board in a very confined space, this arrangement has proved to be the most dangerous.

In dealing with this question of safety to attendants it has to be again considered whether it is better to mount the switches and instruments directly on to the iron framework, and to merely insulate them therefrom by

porcelain or other suitable insulators, or to interpose marble or slate panels between the switch insulators and the iron framework supports.

It is generally agreed that in either case the actual framework should be thoroughly connected with a good earth, and some engineers are of opinion that all metal parts not actually forming part of the live circuit should also be connected to earth. Others, however, think that advantage should be taken of the double insulation afforded by slate or marble between, and in series with, the porcelain insulators supporting the high-tension connections. It must be admitted that the latter arrangement affords the greatest protection from liability to breakdown. The insulation between the live connections and all other parts must in either case be as perfect as it can be made. If this precaution is not taken when all the cases of instruments, etc., are connected to earth, a fault in any piece of apparatus may result in a short circuit on the whole system, and may necessitate the supply being cut off until the faulty apparatus is removed. If, on the other hand, all cases, etc., are insulated from earth, a failure of the insulation on any piece of apparatus will not affect the supply, but the risk of an attendant getting a dangerous shock is considerably increased.

A third alternative is to connect all the cases of instruments and parts of switches, etc., to earth through a fuse, and to shunt this fuse by the primary winding of a small transformer, across the secondary of which a few danger lamps are connected. These lamps may be fixed at different points on the board, in such positions as to be instantly seen by the attendant should they become lighted. It will be obvious that, in the event of the insulation breaking down between the high-tension connections and the cases, etc., referred to, the high-tension current will flow to earth through the fuse, which it will probably melt; the primary winding of the transformer will thus be inserted in this circuit, and the danger lamps will instantly indicate that the parts of the switchboard supposed to be at earth potential have become highly charged.

As a further protection the attendants should be instructed to use gloves when cleaning the cases of high-tension instruments, etc., and the operating handles of the switches should be as efficiently insulated as if the handles themselves were always charged to a high potential. Instructions should also be given that an attendant must on no account handle any portion of the high-tension circuit, supposed to be dead, without first efficiently connecting it to earth. The American and Continental practice of connecting low-tension instruments across the secondaries of series transformers instead of inserting instruments in the high-tension circuit has much to commend it.

Frequent troubles have arisen through earth connections not being of sufficiently low resistance. It is advisable to test the resistance of earth connections periodically. A convenient method of doing this

is described in Chapter VIII. The earth-plate should, if possible, be laid in earth that is always wet, and the connection to this plate should consist of a cable large enough to carry a heavy current without risk of fusion.

A number of experiments on earth-plates were carried out a few years ago by the Telegraphen-Ingenieur Bureau.[1] It was found that where wet earth could not be reached the best earth consisted of an iron cable laid in a mass of lump coke, the two ends being brought out and connected together.

Another form of accident to be guarded against is that due to a possible mechanical injury. Care must be taken, for instance, that automatic cut-outs and apparatus of this description, liable to fly open at any moment without warning, are placed in such a position that it will not be possible for them to fall on an attendant's head or otherwise subject him to injury.

Accidents have sometimes arisen through an attendant closing a switch at some other part of the system, and so charging a conductor, upon which a second attendant is working, to a dangerous potential. If the precaution has been taken to connect this conductor to earth, as recommended above, it is probable that no serious injury will result, but it is advisable to guard against an accident of this description by locking, in an open position, switches controlling this section, and allowing the man working on the mains to retain the keys of the switches.

**Duplication.**—It is often advisable to duplicate some of the important parts of a switchboard, but care should be taken that this duplication is not carried to such an extent as to lead to complication. The advantage of a certain amount of duplication is twofold. In the first place, it is necessary, or at least advisable, to make some arrangements whereby any portion of the board may be made dead for cleaning or overhauling purposes; and in the second place, it is often convenient to be able to divide the circuits into at least two groups, feeding some from one set of generators and some from another. All the duplication required on a main switchboard can usually be confined to the 'bus bars, and as a rule the only additional apparatus required is a two-way switch or plug connection to each generator or feeder, and some form of bar coupling switch. Duplicate fuses are also in some cases useful to allow the working fuse to be removed for examination without cutting off the supply.

**Accessibility.**—The importance of arranging all parts in such a manner as to be readily accessible is recognised in all engineering design. It is, however, of even greater importance in the design of switchgear than of any other apparatus. It should be remembered that in many cases a board can never be made entirely dead, and to attempt to work on a live board upon any parts which are at all inaccessible entails very great danger.

[1] *Archiv Post. Tele.*, iii. pp. 69–75 (1898); *Science Abstracts*, vol. i. p. 1186.

**Standardisation.**—All panels, fittings, and instruments should be made as far as possible to one standard, so as to be absolutely interchangeable one with another. Provision should always be made for extensions to either the generator or feeder panels, and it should be possible to carry out these extensions without serious alterations to the existing board, and without cutting off the supply.

**Concentration *versus* Isolation.**—This is a question upon which a considerable amount of difference of opinion exists. It is undoubtedly very convenient to concentrate all the switchgear into as small a space as possible, in order that the attendant in charge may be able to see all the instruments from one position, and operate any of the gear from there. So long as everything goes smoothly, there appears to be no objection to this arrangement. Should, however, a failure occur at any point of the board, there is a great risk of its affecting adjacent sections and leading to a complete shut-down.[1]

To guard against this some designers have thought it best to distribute the switchgear over the entire length of the generating station, placing each section directly opposite the generator it controls, and consequently several feet away from adjacent sections. This arrangement is, of course, not so convenient for working.

A third alternative is to leave a good space between each switch and to control these from one point, either by means of levers, shafts, and connecting links, as in the case of the Berlin switchgear (see Chapter VII.), or by some electrically controlled devices such as are used in connection with many of the American systems. The latter arrangement appears to work admirably, and the author gathered from conversations with some of the engineers responsible for the smooth running of the very large electricity supply undertakings in the States that this method of control has proved absolutely reliable and satisfactory. It is probable, however, that for installations of a few thousand horse-power only, some simple method of mechanical remote control will be generally preferred.

The views of American electrical engineers on this question cannot be better expressed than by quoting the following extract from a paper by Mr E. W. Rice, Jun., read at the Buffalo Convention of the American Institute of Electrical Engineers in 1901 :—

> "The switchboard should preferably be placed in a separate room, so that any accident to the engines or to the steam piping will not injure the switchboard operator or the switchboard mechanism. The electrical conductors from each dynamo should be led to the switchboard as far apart as possible from those of other units. Each set of conductors should be led to its own switch. Each

[1] Since the above was written, the Bristol fire has emphasised the necessity of efficiently isolating the respective sections of high-tension switchgear.

switch should be of ample capacity to interrupt the entire output of the generator at full voltage, and even take care of the concentration of the entire load of the station, as in a short circuit. This switch should be placed in a cell of fireproof material, and preferably electrically controlled from a central point. If so disposed, these switches may be placed reasonably close together, but the partitions should be such that any one of the switches could arc to destruction without involving the switch of a neighbouring generator. Switches should be in duplicate, so that, in case of failure of one, another switch will be in readiness. Especial care should be taken, in leading the conductors from the switches to the 'bus bar, to keep the conductors as far as possible from those of neighbouring units.

"The 'bus bar or bars should preferably be in duplicate, or some equivalent arrangement, such as sectional subdivision, should be adopted. 'Bus bars should be carefully protected in fireproof compartments so arranged that it would be impossible for any arc to short circuit from one conductor to another. The same care should be taken to isolate the conductors leading from the 'bus bars to the feeder switches. The feeder switches should also be in duplicate—that is, two separate sets of switches on each feeder in series with each other when feasible, or the conductors leading to a group of feeders may be joined together by a switch placed in series therewith, controlling a group of feeders. Each group switch and each of the feeder switches should be mounted in its own separate fireproof compartment, and preferably controlled electromagnetically from a distance. The conductors leading from the feeders out of the station should not be massed together in one conducting trench or well, but should be subdivided into as many groups as circumstances will permit.

"The constant aim throughout the entire station should be to limit the normal flow of energy in a given space to a predetermined amount, preferably, for example, to that of the generator unit which has been selected; or, in the case of the feeders leading outside the station, the normal flow of a group may be limited to that delivered to any one sub-station.

"It is obvious that the arrangement of switchboard as described will occupy more space than the ordinary panel type. The total space occupied, however, is but a small portion of the total space required for the generating plants. Such separation of the switches, etc., makes some method of control from a distance very desirable. The motors used for operating the switches may be either pneumatic or electric. The control of these motors should

preferably be electric in all cases. By adopting electric control from a distance, it is possible to combine all the switches required for the generator, feeders, etc., upon a small keyboard under the observation and control of a single operator. It is also possible to place this operator in such a position that he will have a comprehensive survey of all the measuring and controlling devices needed for the station, and at the same time be free from danger in case any of the apparatus should fail to perform its work. Under such circumstances the operator is much less liable to make a mistake, and it is believed that, having taken such precautions, accidents even of a trivial character will be more unlikely to occur. In laying out the electrical devices for such a station the utmost simplicity should be aimed at, not a single instrument, conductor, or switch being placed in the station that has not been carefully considered and felt to be essential. It is better to err on the side of simplicity than of complexity."

**Capital Expenditure.**—This is a matter which must not be lost sight of, though the curtailing of expenditure on switchgear should be tempered with reason. Small stations of two or three thousand horse-power should certainly not be handicapped with a heavy capital outlay on this account, and it would be absurd to use in these small stations such elaborate systems of electricity control as have been installed in some of the large American stations. It would, on the other hand, be equally short-sighted policy to starve the controlling arrangements in those stations where the damage caused by one interruption of the supply would, in many cases, amount to more than the entire capital expended on the switchgear.

**Position of Switchboard.** — The usual practice in this country is to erect both the generator and the feeder switchgear on a gallery raised a few feet above the engine-room floor, and in such a position as to enable the attendant to obtain an unobstructed view of all plant under his control. There is, however, much to be said for the contention that the switchboard attendant should be in a position where he is not liable to be affected or unnerved by any such catastrophes as the stripping of an armature, the bursting of a steam pipe, or the general smashing up of an engine, occurrences which, though happily rare, are always liable to occur. After all, if some simple system of signalling is installed for communication between the switchboard attendant and the engine attendant, and the switchboard is equipped with instruments to indicate the behaviour of each generator, what more is required? Cases have undoubtedly occurred where, owing to the generators being in full view of the switchboard gallery, the attendant has operated the wrong switches as the result of acting in a hurry upon what he has seen in the engine-room, instead of being guided by the indicating instruments.

## CHAPTER II.

### CONSTRUCTIONAL DETAILS.

The use of connectors, switches, and circuit-breakers—Connectors and switches required to carry full load current without heating—Circuit-breakers further required to break full load current without excessive arcing—Respective advantages and disadvantages of various types of connectors—Various forms of contacts for switches and circuit-breakers—Insulators: the use of slate, marble, ebonite, mica, porcelain, etc.—The arrangement of regulating rheostats—Types of rheostats: 'Ward-Leonard,' 'Brush,' 'Ferranti,' 'Cowan,' 'Westinghouse,' etc.

The success of any system of electricity control is, in a very great measure, dependent upon the attention that has been paid to the details of construction. The points requiring the greatest attention are probably those portions of the system which form part of the conducting circuit other than the actual conductor. There can be no doubt that the best conductor for an electric current is a copper bar or cable, but it is unfortunately necessary for purposes of manipulation to insert in the circuit devices by means of which the continuity of the circuit may be broken. Some of these objectionable necessities may be merely connectors bolted to the conductors, and only used in erecting or carrying out alterations to the system. It is, however, also necessary to include other devices by means of which the circuit may be opened daily or oftener, and for this purpose switches or circuit-breakers are used.

In the United States it has become customary to define a 'switch' as a device corresponding to a plug for directing the flow of current. A switch, under this phraseology, is never used to interrupt the circuit when it is carrying a heavy current; for the latter purpose 'circuit-breakers' are used. These may be operated automatically or by hand.

It will be evident that all that is required of a connector or switch is that it should carry the maximum current for an indefinite period without appreciable heating. A circuit-breaker must be equally capable of fulfilling this requirement, and it must in addition be capable of interrupting the circuit when carrying the maximum current without excessive arcing or other disturbing effects. The latter requirement has provided a most difficult problem. The manner in which it has been dealt with by different designers is illustrated and described in Chapter III.

**Terminals or Connectors.**—The current-carrying problem is comparatively simple, and has been successfully dealt with in various ways. A few of the solutions to it are given below. One of the simplest forms of connectors is shown in fig. 3. The surface of each of the faces in contact should not be less than one square inch per hundred amperes if constructed of brass or gun-metal, and the faces must be accurately tooled to ensure absolute contact being made over the entire surface. This type of connector is perfectly satisfactory for use in connection with direct current systems, but it is liable to give trouble when used in alternating current circuits, owing to the fact that any conductor carrying an alternating current is in a continual state of vibration, and although this vibration is

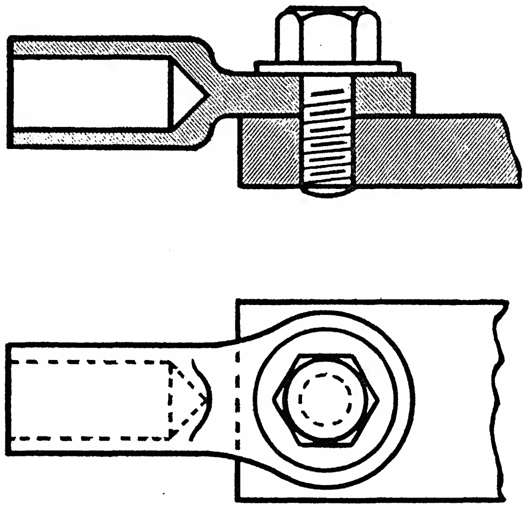

Fig. 3.—Flat-face cable connector.

barely susceptiblé to the touch, it is quite sufficient to cause nuts and bolts to gradually work loose. As a perfect contact depends upon the faces being forcibly pressed together, the loosening of the bolt holding these faces together will cause the contacts to become very hot, and this heat will be transmitted to the socket into which the cable is sweated, causing the solder to melt, and possibly ending in the circuit being opened at this point, with disastrous results. Even the use of lock-nuts cannot be relied upon to prevent the bolts from working loose, though a Thackeray washer between the head of a bolt and the eye of a connector may do so.

As a further precaution it is advisable to support cables independently of the contacts, so that, should the solder be melted, the cable will not drop away from the connector. The cable should also be a good fit in the socket, and not, as one often sees, a cable half the diameter of the socket, the difference being made up with solder.

The cone form of connector, shown in fig. 4, has the advantage that a good contact may be maintained for a time if the tightening nut has worked loose, but it is dependent upon the taper of the plug and socket

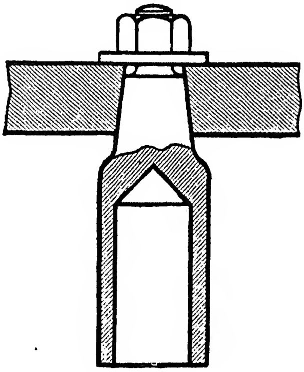

FIG. 4.—Coned plug cable connector.

portions of the connector being of precisely the same angle as each other throughout.

A very reliable form of connector is illustrated in fig. 5. This consists of a split cable socket which has been bored with a parallel hole of

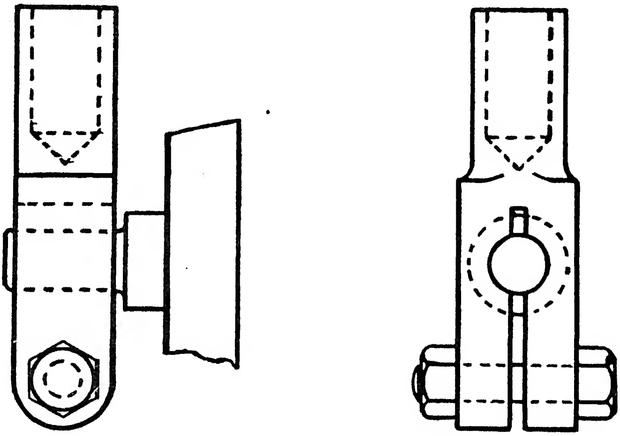

FIG. 5.—Self-locking cable connector.

slightly smaller diameter than that of a turned pin projecting from the metal block to which the cable is to be connected. It will be evident that when the socket is forced upon the pin the tension upon the latter, due to the split socket, will be sufficient in itself to make a good contact. As a further precaution, the ends of the split connector are bolted together,

thus increasing the grip upon the pin. The nut and bolt in this case will be prevented from working loose by the tension upon them due to the divided parts of the socket being compressed together, the effect being very similar to that of the Thackeray washer.

A form of connector designed by the author is illustrated in fig. 6. This has been used for making connection between cutouts and the low-tension 'bus bars in sub-stations. The 'bus bars consist of two copper strips about an inch wide by a quarter of an inch thick. These bars are supported by a projection cast in one piece with one of the

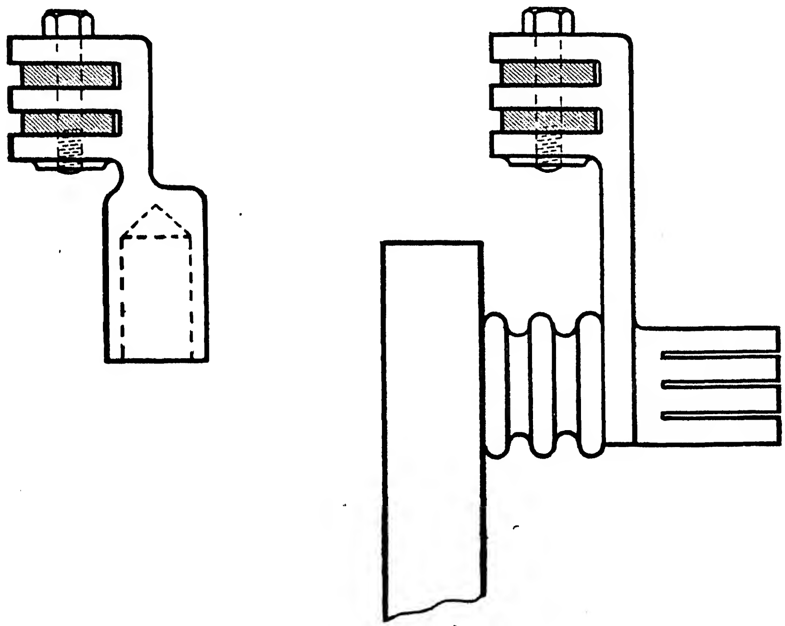

Fig. 6.—'Bus bar connector.

contacts of the cutout to be connected to the bars. By this means independent insulators for supporting the 'bus bars are rendered unnecessary. The connector is slotted out to be a tight fit on the 'bus bars, and as an additional precaution a set screw is run through the connector and bars. It will be seen that this connection cannot be broken except by first taking out the set screw and then removing the cutout bodily from its position. It is therefore impossible for the circuit to be opened accidentally. Similar connectors are also used for connecting cables to the 'bus bars, the cable socket in this case forming part of the connector.

A form of connector that is very liable to give trouble when used for carrying heavy currents is an ordinary large terminal, particularly if, as one often sees, the hole in the terminal is much too large for the cable.

Where this is the case it is advisable to increase the diameter of the cable by binding wire round it until the cable is a good fit in the terminal. A useful device for terminal connectors is shown in fig. 7. In this arrangement the diameter of the cable is increased to fit the hole in the terminal

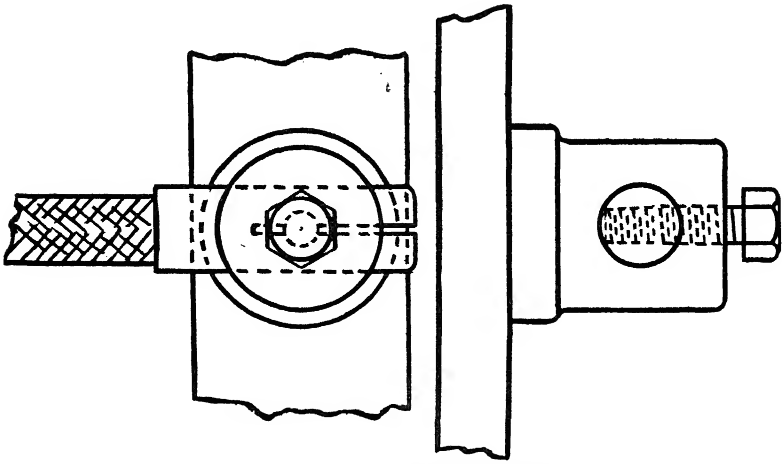

FIG. 7.—Self-locking terminal thimble.

by means of a socket sweated to the end of it. This divided socket is placed in the terminal and a hole is drilled through it, to allow the clamping bolt of the terminal to pass through the socket instead of merely clamping it as in an ordinary terminal. The hole is tapped with the same

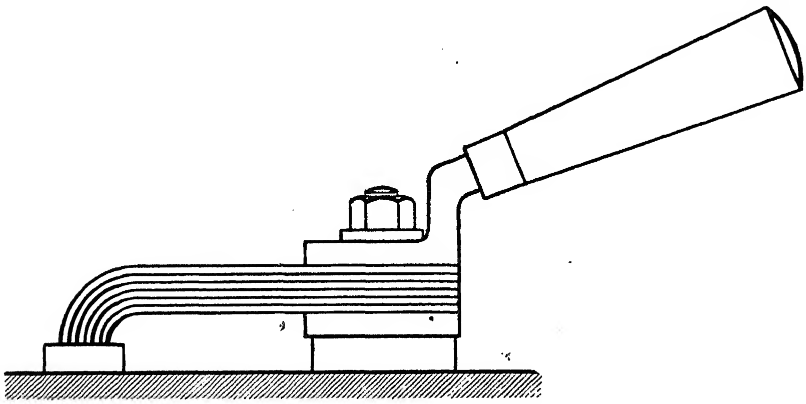

FIG. 8.—Laminated brush switch.

thread as the clamping set screw. The latter, however, is slightly tapered, so that as it enters the hole in the split socket its tendency is to expand the socket in the terminal.

**Contacts.**—The contacts of switches and circuit-breakers cannot as a

rule be bolted together. Consequently it is necessary to resort to other means to ensure a good metallic connection being made between the opposing faces of the contact. The usual procedure is to take as one member of the contact a non-elastic block of metal, and to rigidly fix this to the base of the switch. For the other member one or more metal plates are provided, which make spring contact with the solid block. It is usual to use a number of such plates, thus ensuring that there shall be many points of contact at the junction.

A contact of this description is shown in fig. 8. It will be seen that

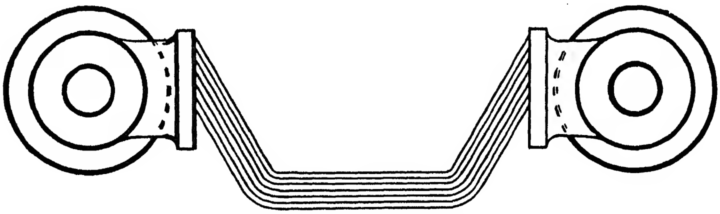

FIG. 9.—Laminated contact piece connecting solid contacts mounted on insulators.

the current has to pass through the spindle supporting the laminated contact, and this is undesirable when heavy currents have to be carried. A somewhat better arrangement is shown in fig. 9. In this case the cables are connected to two terminals, and the laminated contact used for completing the connection is carried on insulators supported from the movable arm of the switch. Even this arrangement is not free from defects. The metal blocks to which the cables are connected are usually supported on corrugated porcelain insulators, the block being secured to

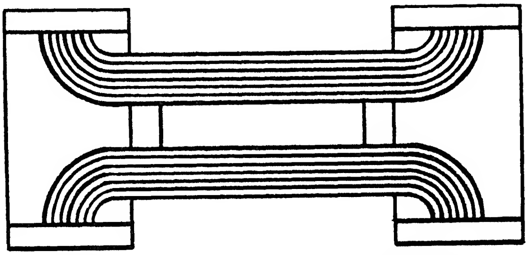

FIG. 10.—An improved laminated contact piece.

the insulator by means of a stud cemented into a hole in the insulator. This form of construction is not as mechanically perfect as it might be. The cement is liable to loosen its hold, particularly if it is affected by heat. One of the blocks may thus be shifted from the position in which it is requisite that it should be rigidly held; the compression between the laminated portion of the contact and the solid block is then lost, and a considerable amount of heating, if not an actual open circuit, is likely to occur.

A very reliable form of contact for carrying large currents is shown in fig. 10. In this arrangement the laminated portions of the contact are, when the switch is closed, compressed between two faces on each of the metal blocks connected to the two ends of the circuit to be completed. It will be seen that in this type the compression on the laminated contacts will be in no way reduced if one or both of the block portions of

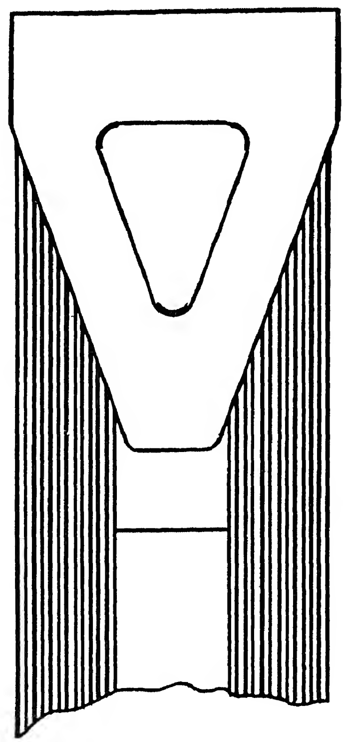

FIG. 11.—Elwell-Parker laminated contact.

the contact become loose in their supports. An example of the application of this type of contact is shown in fig. 41.

For use with automatic circuit-breakers it is necessary that the friction tending to hold the contact in a closed position should be reduced, to enable the circuit to be opened with as little mechanical effort as possible. The Elwell-Parker type of contact, shown in fig. 11, obviously requires very little effort to withdraw the solid taper block from the laminated contact.

Figs. 12 and 13 illustrate types of contact used by many manufacturers, particularly for automatic circuit-breakers. The tension between the contacts is here maintained by the laminated portions of the contacts being

forced against the solid connecting blocks. In fig. 12 the compression is effected by a rotary motion, and in fig. 13 by a parallel motion, a suitable device for operating the latter being a toggle joint, such as shown in figs. 129 and 130.

The Brush Co.'s standard type of contact is illustrated in figs. 14,

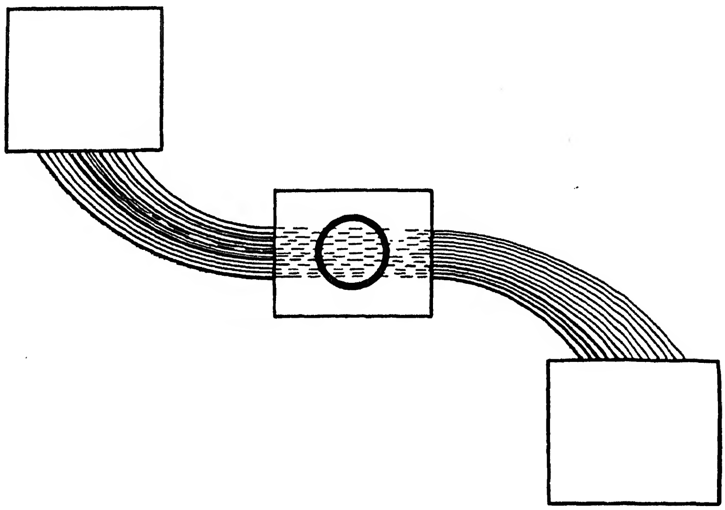

FIG. 12.—'S' laminated brush contact.

15, and 16. This consists of a gun-metal casting subdivided by a number of saw cuts to give it the necessary flexibility. The plunger type depicted by fig. 14 is a satisfactory contact for absolutely parallel movements.

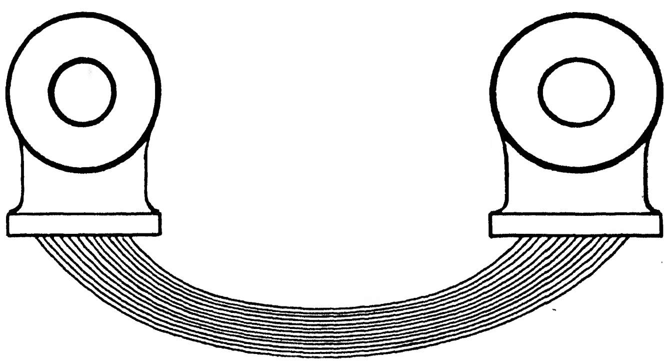

FIG. 13.—Jamb brush contact.

Fig. 15 may be used for parallel or radial movements. The taper form of contact, fig. 16, is used for automatic circuit-breakers and the quick-break trigger switches illustrated in fig. 42.

A type of contact largely used, particularly for carrying heavy currents, is the multiple knife switch contact illustrated in fig. 17. A switch of this description is often used for connecting up sections of 'bus bars, and the extra precaution is sometimes taken of bolting the contact pieces together at both ends of the connecting bridge. This connecting piece is slotted at one end to allow the switch to be opened after slackening the nut on the bolt. This type of contact is used for the five-way feeder switches at the Boston Electricity Works (see Chapter VIII., fig. 166). These switches are in this case constructed to enable the end A to be turned about an axis perpendicular to the panel to which it is fixed. By this means the feeder terminating at A may be connected through any one of five contacts B to any one of the five 'bus bars.

Another excellent type of contact for heavy currents is the Glasgow contact, illustrated in Chapter VIII., fig. 157.

**Insulation.**— Whilst it is of the greatest importance that every precaution should be taken to ensure complete continuity of the conducting circuit, it is equally important to pay the most careful attention to the question of efficiently insulating the circuit from other conductors.

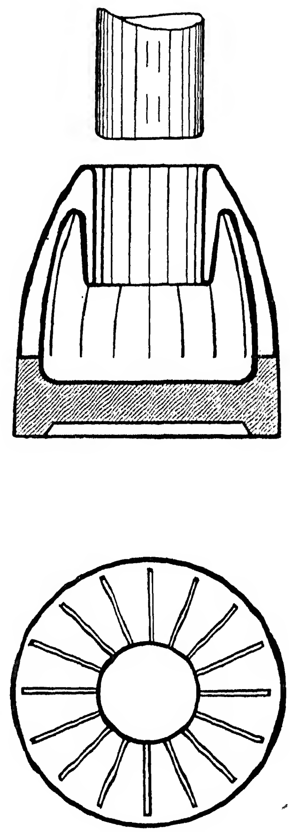

FIG. 14.—Raworth round cast contact.

For pressures up to, say, 600 volts, switch contacts, etc., may be

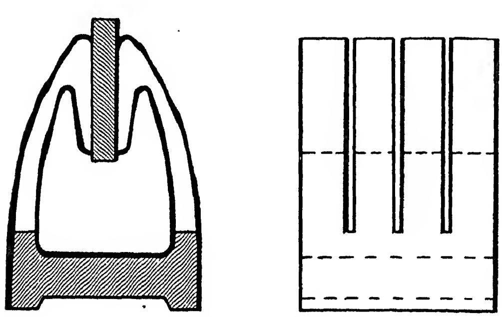

FIG. 15.—Raworth flat contact.

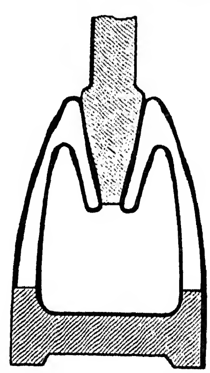

FIG. 16.—Raworth taper contact.

mounted directly on the slate supporting panels; but the insulating properties of slate vary considerably, and it is in consequence not safe to rely upon it for higher pressures, unless the panels have been submitted to a thorough test.

The system of insulating the contacts and terminals of apparatus by bushes and washers of ebonite or like material is not to be recommended.

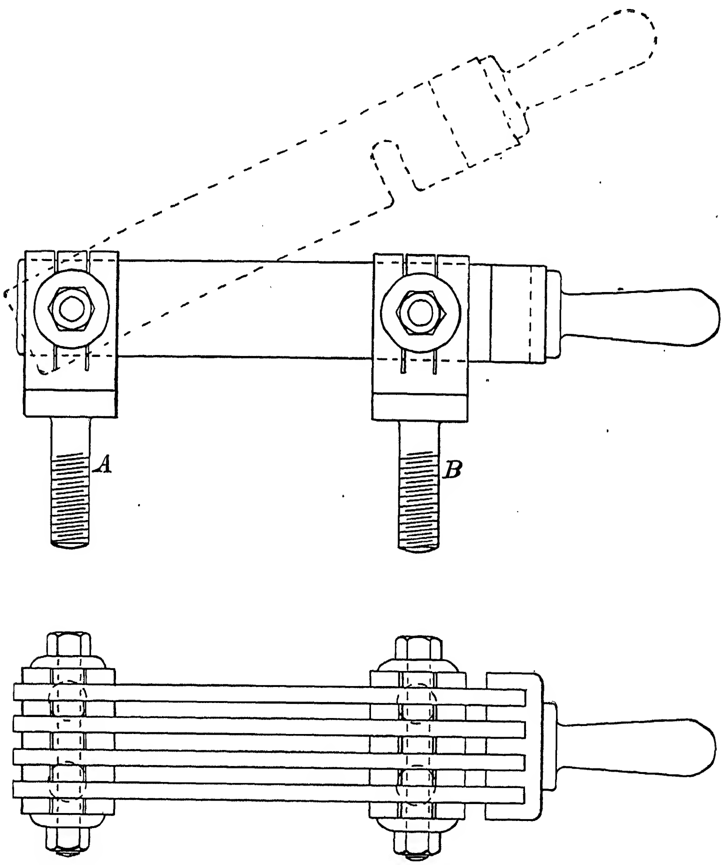


FIG. 17.—Multiple blade contact.

It is expensive and mechanically deficient. It is better to subject the panels of slate or marble to a severe test after drilling and mounting.

It must be remembered, in considering the relative merits of marble and slate, that, apart from any æsthetic question, the latter is cheaper in first cost as well as in drilling. It has also a specific insulation that is amply sufficient for pressures up to 600 volts.

A carefully selected block of marble that has been well boiled in paraffin

wax, until the pores of the marble have been thoroughly impregnated therewith, is sometimes used for pressures up to 2000 or 3000 volts. Marble so treated is, however, very likely to crack in the process of impregnation, and can only be used in positions where it is not liable to be subjected to any great mechanical shock or strain.

Considerable difficulty has always been experienced in obtaining an insulator that is a perfect non-conductor, and is at the same time mechanically strong.

Ebonite is an excellent insulator, but unless it is well polished, surface leakage may take place, added to which, its insulating properties are liable to be greatly reduced by careless tooling. It is also somewhat inflammable, softens at a low temperature, and is expensive to use in large quantities. A number of excellent substitutes for ebonite have been placed on the market, which are cheaper, and at the same time can be moulded into the shapes required, thus rendering tooling unnecessary. Ambroin, vulcabeston, and moulded mica may be mentioned as some excellent substitutes for ebonite.

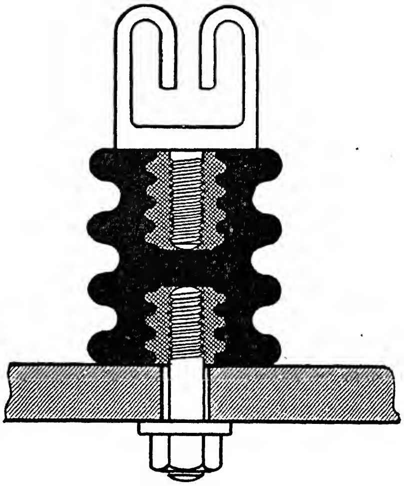

FIG. 18.—Corrugated porcelain insulator.

For non-penetration, mica is the best insulator it is possible to obtain, but the raw material is very liable to flake. A material known as micanite, consisting of thin mica strips stuck together with shellac, is very largely used for many purposes. This material is made up into tubes and a variety of other shapes.

For supporting high-tension connections, porcelain or glazed earthenware is almost universally used. It is generally moulded into corrugations, as shown in fig. 18, to increase the surface, and thus reduce the tendency to surface leakage.

On the Continent the petticoat type of insulator illustrated in fig. 19 is generally used for supporting the high-tension 'bus bars and switchboard connections.

**Resistances.**—A further detail of importance is the construction and arrangement of the resistances used in almost every scheme of electricity control. If, as usually happens, these are required to be adjustable for regulating purposes, they should be arranged in combination with the regulating switch when possible, so as to avoid the mass of connecting

wires between the switch and resistance necessitated by the latter being fixed some distance away from the switchboard. A very convenient arrangement is that illustrated in connection with the Edinburgh switchgear (fig. 153), where the resistances are supported underneath the switchboard, directly below a pillar fitted with a hand-wheel for controlling the switch, which is mounted on the resistance frame.

In some of the large American systems the resistances are placed in any convenient position away from the switchboard, and the regulating switch is

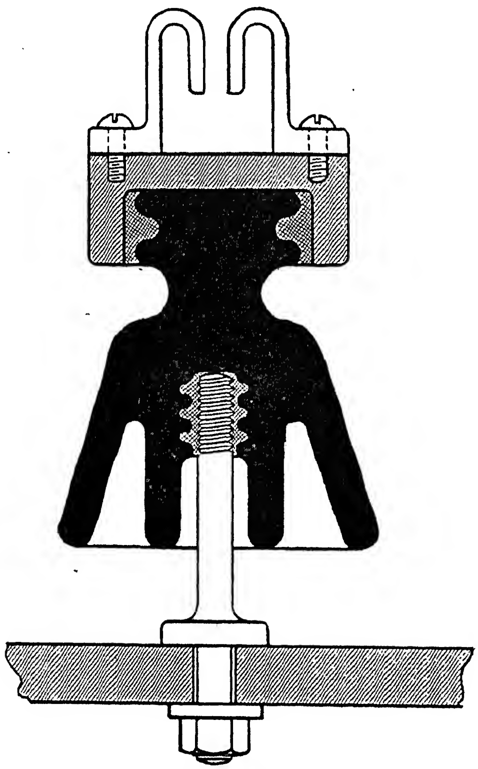

Fig. 19.—Petticoat insulator.

operated by an electric motor controlled from the switchboard. Fig. 20 illustrates the Westinghouse Co.'s standard electrically operated field rheostat.

In cases where the energy to be dissipated is not excessive, the resistances may be arranged as in the Ward-Leonard system. In this rheostat the heat generated in the resistance wire, by the passage of a current, is not radiated directly from the surface of the wire, but is rapidly conducted to a supporting plate, which becomes the radiating surface. This is accomplished by the use of enamel, which attaches the wire to, but insulates it

from, the radiating surface plate, and which also completely surrounds the wire, and protects it from chemical action. In this way the capacity of a small resistance wire is greatly increased. In practice it is found that a wire that will carry a certain current when exposed to the air will carry several times that amount safely in this rheostat. On this principle, since the cross-section can be greatly reduced, it follows that its length can also

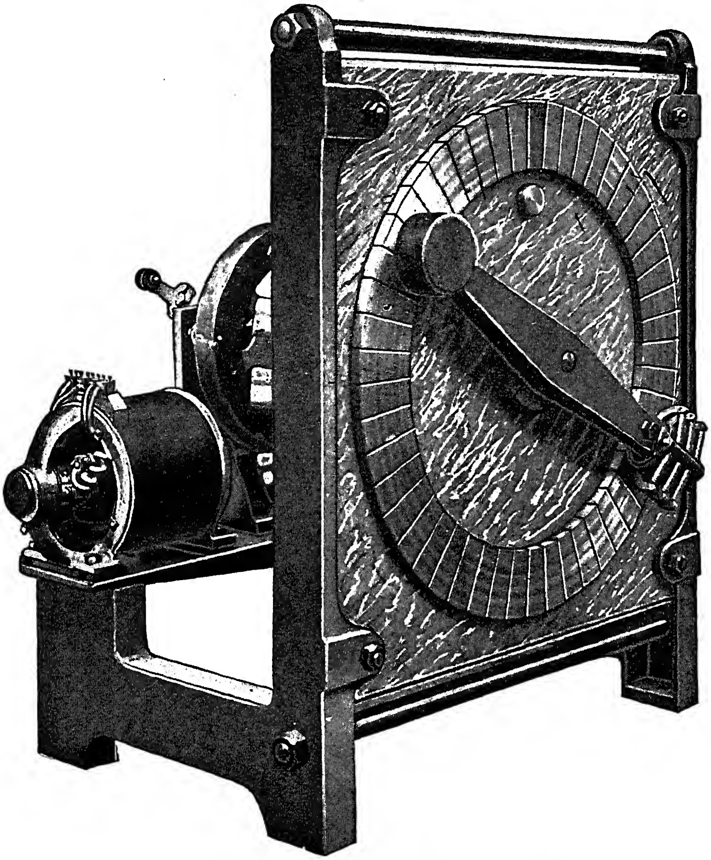

FIG. 20.—Westinghouse motor-driven rheostat.

be proportionately shortened for any required resistance. No consideration as to the mechanical strength of the wire enters into this construction, since it is so perfectly protected and supported on all sides.

To increase the radiating surface, the back of the plate is provided with ribs. The makers claim that these plates will dissipate continuously $2\frac{1}{2}$ watts per square inch of surface. Fig. 21 shows the general construction of this rheostat, and fig. 22 shows diagrammatically how the wire or strip is

supported in the enamel. It is obvious that a number of these rheostat plates may be mounted together on one frame at the back of a switch panel

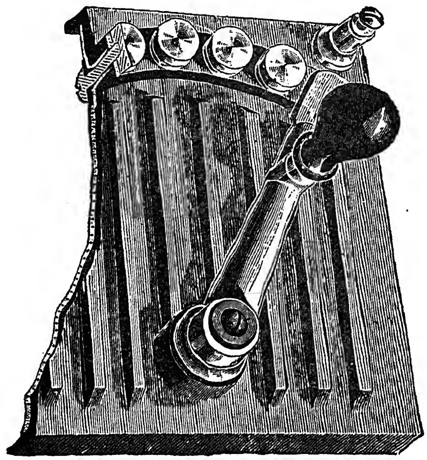

FIG. 21.—Ward-Leonard rheostat (front view).

and controlled by one handle. Two circular plates mounted in this way are shown in fig. 23.

An objection to this type of resistance is the impossibility of repairing a

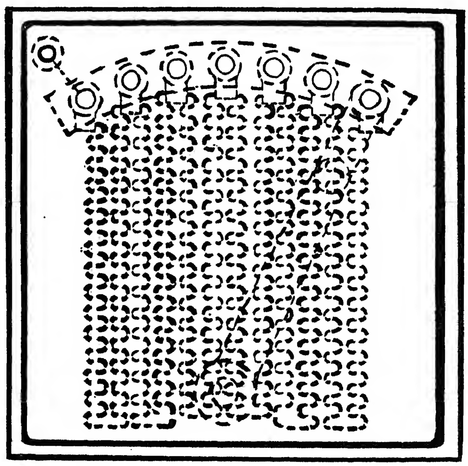

FIG. 22.—Ward-Leonard rheostat (back view).

broken-down rheostat. This may become serious if large plates are used, but is reduced by dividing the rheostat into sections, as shown in fig. 23.

The practice of placing resistance coils some distance from the switchboard and of running connections therefrom to a multiple step regulating

switch on the switchboard has now become practically obsolete The chief objection to this arrangement was that it entailed the use of a large number of connections between the switch and the resistance coils, thereby increasing complications, added to which, there was always the danger of one of these connections becoming loosened and opening the circuit.

The type of rheostat adopted as a standard by the Brush Co. is illustrated in fig. 24. The resistance wire is wound in one continuous length upon rectangular blocks of slate notched at the corners to maintain definite spacing between the wires. The wires at one end of the slates are

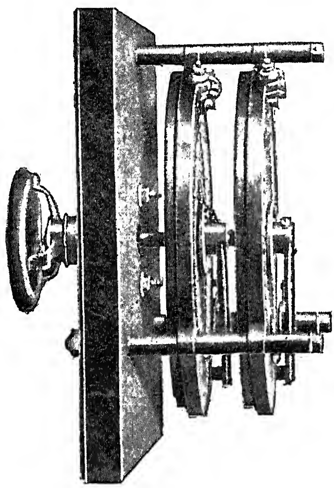

FIG. 23.—Ward-Leonard multiple rheostat.

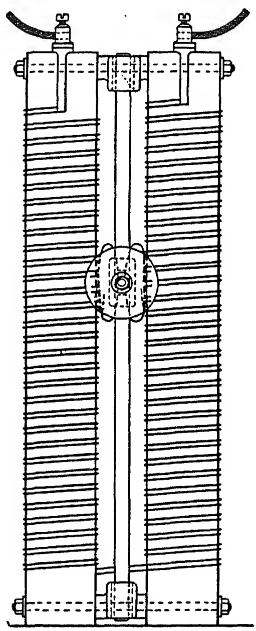

FIG. 24.—Brush rheostat.

permanently connected together, and at the other end are connected in series with the circuit to be controlled. A movable brush is free to slide up and down a vertical guide rod. This brush short circuits all the resistance below it. An objection to this type of rheostat is that the continuous rubbing of the brush on the surface of the wire is liable to weaken this, and eventually cause it to snap and open the circuit; a further objection is that a large proportion of the heat in the resistance wire is transmitted to the slate and radiated by this. Should the rheostat be seriously overloaded for an appreciable time, the slate may be raised to such an excessive temperature as to cause it to crack.

A somewhat similar type of rheostat to the above is the Ferranti field regulator, shown in section in fig. 25, and in perspective in fig. 26. In

this case the resistance wire A is carried on an iron framework B, but insulated from the latter by porcelain troughs C. The heat is by this means dissipated without injury to the insulating supports. A brush D is used for short circuiting a portion of the resistance wire, but this brush does not rub directly on the wire, but on a number of independent metal blocks, each held in its proper position on the back of the porcelain trough by one turn of the resistance wire, the latter dropping into grooves in the blocks.

It is evident that, when rheostats of the type illustrated in figs. 24–26 do break down, the repairs are somewhat difficult.

The Cowan rheostat, illustrated in figs. 27–30, has been designed to cope with this difficulty. This rheostat is

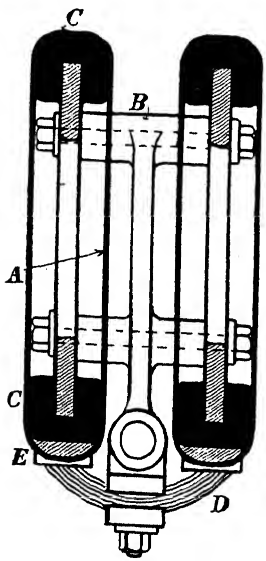


Fig. 25.—Section of Ferranti rheostat.

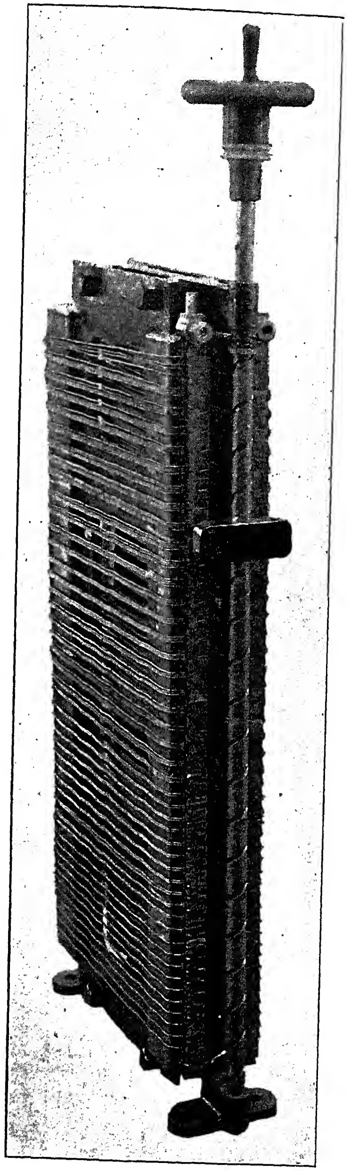

Fig. 26.—Photo of Ferranti rheostat.

built up of a number of resistance units. These units are all made to a

standard pattern, and should one of them break down, it is a very simple matter to replace it by a spare one. Fig. 30 is reproduced from a photograph of one of these units. Figs. 27 and 28 show respectively a back and front view of a complete rheostat. These rheostats are usually fixed beneath the switchboard gallery, and controlled by a hand-wheel supported by a pillar on the gallery, as shown in Fig. 29. The pillars are provided

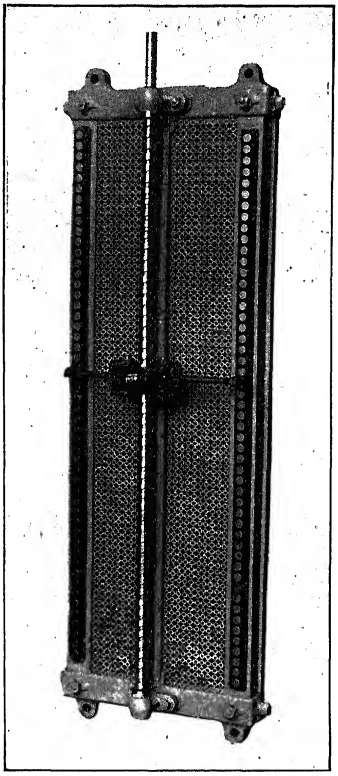

Fig. 27.—Cowan rheostat (front view).

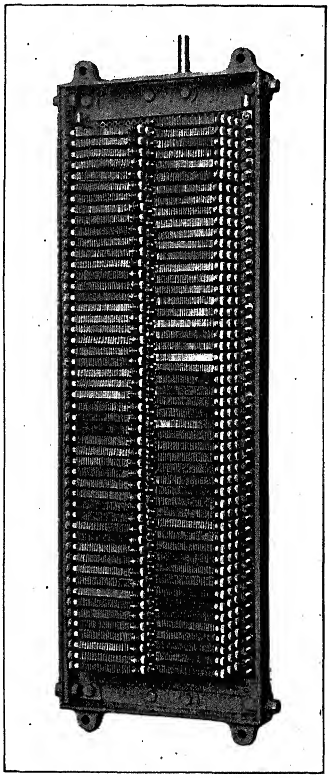

Fig. 28.—Cowan rheostat (back view).

with indicating pointers to show the position of the cursor, and in some cases with field ammeters.

Messrs Cowans, Limited, have recently introduced an interesting resistance unit for heavy currents. One of these units is illustrated in figs. 31 and 32. Each unit consists of a cast-iron rectangular tray lined throughout with asbestos slate. Two stout copper strips C C (fig. 32) are laid on opposite sides of the tray, with one end of each strip projecting through slots in one end of the tray. These copper strips form the terminals of each unit to which the ends of the high resistance strip are riveted. Strips

of asbestos slate S S are used to separate the layers of resistance strip. The trays are finally completely filled with sand. This serves to keep all parts rigidly in position, and materially assists in the dissipation of the heat. The cast-iron cover is cemented and bolted on to the tray One of these units, about 18 inches square, will successfully dissipate 10 H.P. for 10 minutes. The usual method of assembling them to form a rheostat is to build up a number of them in one frame, connecting each one to a segment switch placed on the top or at one end of the frame.

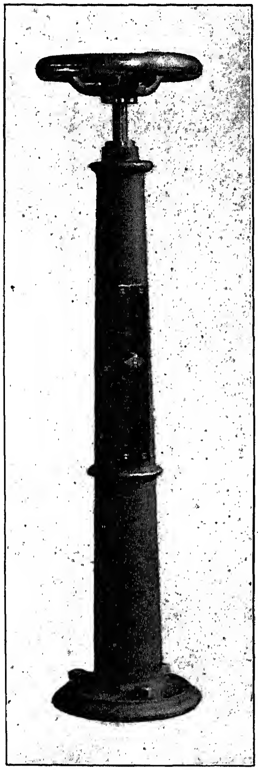
FIG. 29.—Controlling pillar of rheostat.

Another example of a rheostat built up of resistance units is that of the Electric Controller Co.'s reversible controller for crane motors, etc. Fig. 33 shows one of this company's standard resistance units. The resistance wire is wound on a heavy asbestos tube placed over a wrought-iron core. The rear end of the core is provided with a cap of insulating material C which is unaffected by heat, and which securely holds one end of the resistance wire B. Two nuts F are also provided on this end of the core for clamping the parts of the unit in place. These nuts constitute one terminal of the unit. At the other end of the asbestos tube is placed a cap of copper D, which is electrically connected to the iron core, and is also adapted to receive and hold the other end of the resistance winding. By this method of construction both ends of the resistance winding are brought to the rear end of the coil, thus greatly simplifying the necessary connections.

The iron core is extended beyond the copper cap and is adapted to pass through the slate face of the controller, where it is held in place by a lock-nut working in a countersunk recess in the slate. The contact button, or segment, screws directly on the end of the iron core above the lock-nut. These buttons have octagonal heads, which may be easily grasped with a wrench. It will be seen that in this way a button may be removed and replaced without disturbing the resistance unit and its connections. It will also be observed that the turns of resistance wire form the exciting winding of an electro-magnet, of which the iron rod at the centre of the coil forms the core. When current passes through the coil, the core

becomes magnetised with one pole at the centre of the contact button. This places the contact button in a powerful magnetic field, so that any

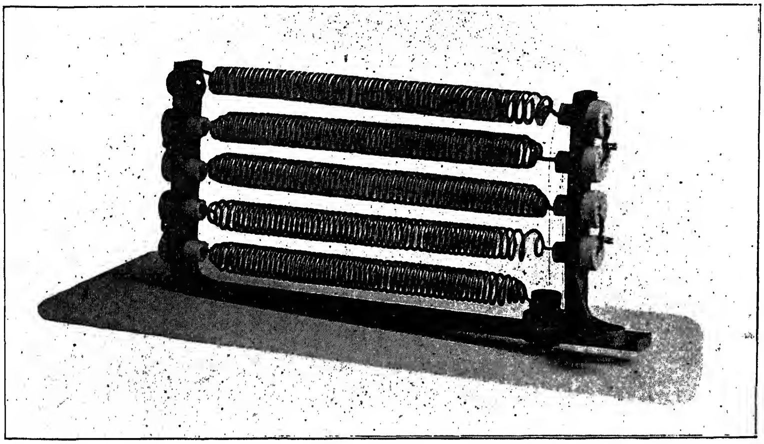

FIG. 30.—Single unit of Cowan rheostat.

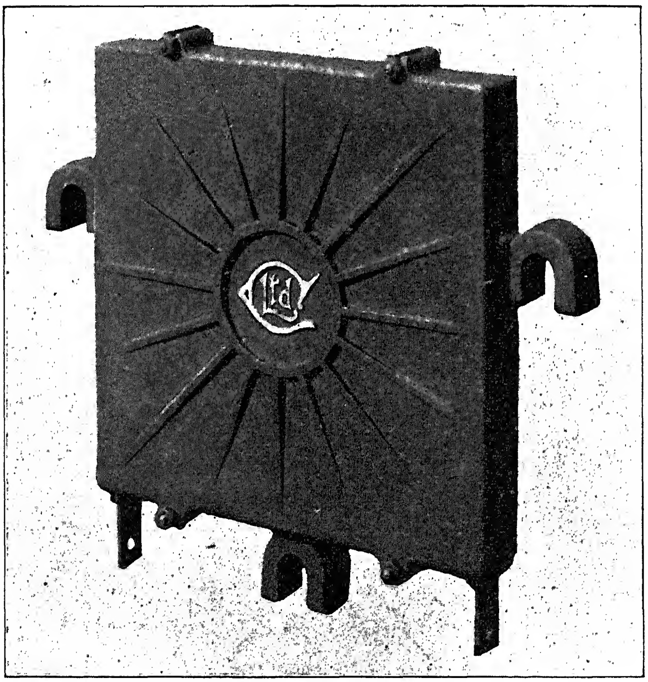

FIG. 31.—Single unit of large capacity Cowan rheostat.

arc which may be formed will be instantly ruptured. Further, when the

current is heavy and the danger of arcing increased, the magnetic field is

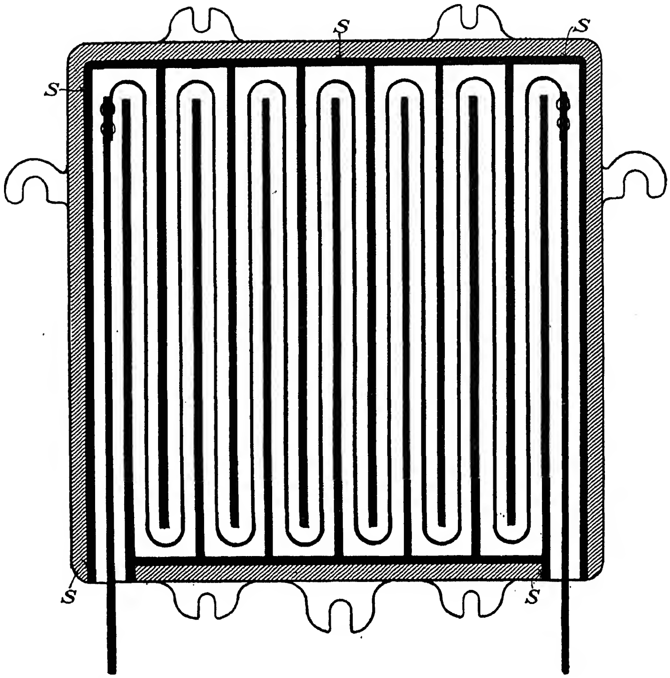


FIG. 32.—Diagrammatic view of interior of fig. 31.

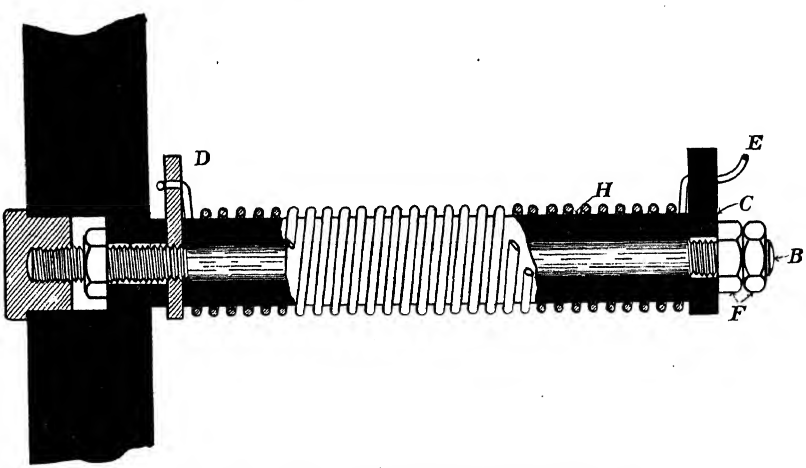


FIG. 33.—Single unit of Electric Controller rheostat.

stronger, thus adjusting itself to the demands upon it. This blow-out

feature is secured without complicating or adding to the size of the controller.

A somewhat unusual type of rheostat is to be seen in the Paderno generating station near Milan, for regulating the fields of the generators. The resistance wires and strips are built up somewhat on the lines of a squirrel cage, mounted on a shaft and provided at one end with a commutator to which the various sections of the rheostat are connected. Fixed brushes making contact with the commutator are connected in series with the field circuit. To cut resistance in or out, the entire rheostat is rotated by an extension to the shaft, terminating in a handle on the switchboard.

# CHAPTER III.

## CIRCUIT-BREAKERS, OR CURRENT-INTERRUPTING DEVICES.

Various methods of breaking an arc:—Quick break, Carbon break, Water break, Magnetic blow out, Shutter break, Oil break, Multiple break, etc.—Prof. Hopkinson's experiments—Respective functions of manual, mechanically operated, and fusible circuit-breakers—Field circuit-breakers, constructed to insert resistance or short-circuit field on opening—Examples of quick break circuit-breakers: 'Mordey,' 'Westinghouse,' etc. — Examples of water break circuit-breakers: 'Raworth,' 'Cowan,' 'Brush,' etc.—Examples of blow-out circuit-breakers: 'Fowler,' 'Bates,' 'Schuckert,' 'Stanley,' 'Cowan,' etc.—Horn break circuit-breakers—Experiments to show that their action is not due to heated air—Theory explained—Modified arrangement of horns—Blow-pipe action of horn break fuse—Liability to induce surgings in high-tension cables—Carbon-tipped horn break circuit-breaker—'Siemens' plunger circuit-breaker—'Partridge' vacuum circuit-breaker—'Partridge' sparklet fuse—Examples of oil break circuit-breakers: 'Ferranti' H.T. oil fuse, 'Ferranti' extra H.T. multiple oil fuse—'Ferranti,' 'Cowan,' and 'Stanley' oil break switches—'Schuckert' and 'Parshall' multiple break circuit-breakers — Shutter circuit-breaker—'Mordey' dust fuse—Shunted circuit-breakers.

The term circuit-breaker is here used to signify a device for interrupting a current—as distinct from a switch, the use of which is assumed to be confined to directing the flow of current.

Reference has been made in a previous chapter to the difficulties which arise in breaking a circuit carrying a heavy current. These difficulties are proportionally greater in dealing with high-tension currents. A pressure which is insufficient to cause the current to spark across an air gap an eighth of an inch wide is sufficient to maintain the circuit across a gap two or three feet wide when a heavy arc is established. This is chiefly due to the fact that the arc itself becomes a moderately good conductor, owing to the presence of metallic vapour caused by the action of the intense heat produced immediately the arc is established, on the metal contacts.

Various devices have been used with more or less success for overcoming these difficulties. They practically all depend, however, upon one of the following principles:—

(A) The formation of an arc is prevented by very rapid separation of the contacts, thus increasing the gap between the points of contact to a

non-sparking distance without generating sufficient heat to vaporise the metal.

(B) The circuit is finally broken between carbon contacts, or between contacts made of zinc, the vapour of which has less conducting power.

(C) The circuit is broken under water. The temperature is thus prevented from rising sufficiently high to vaporise the metal.

(D) The arc, immediately it is formed, is blown out magnetically, or by means of a blast of air.

(E) A shutter of non-conducting material is interposed in the path of the arc.

(F) The circuit is broken under oil.

(G) The circuit is broken at a number of points simultaneously. By this means the energy to be dissipated on breaking the circuit is divided up instead of being all concentrated on one point; it may thus be insufficient to raise the temperature of all the points of contact sufficiently high to vaporise the metal.

(H) The arc is suddenly cooled immediately it is formed, either by the rapid expansion of air or gas, as in the Partridge switch, or by drawing one of the contacts through a heavy block of metal, as in the Siemens switch.

The method selected for interrupting the arc on breaking a circuit should depend upon the conditions under which the circuit-breaker is to be used. For breaking an H.T. alternating current, a slowly drawn out arc in open air is the worst type, as breaking such a circuit under these conditions causes abnormal rises of pressure throughout the system. For this purpose the best practice appears to be to break the circuit under oil. This instantly interrupts the flow of current without the formation of an appreciable arc. To attempt, however, to suddenly interrupt a direct current circuit by this means is liable to lead to quite as disastrous results as slowly drawing out an arc on an alternating current circuit. The use of oil-break switches on the H.T. direct current circuits at Hull had to be abandoned for this reason.

Prof. Bertram Hopkinson, in his paper on Automatic Circuit-Breakers,[1] publishes the results of some very interesting experiments, from which it appears that even the use of magnetic blow-out circuit-breakers is under some conditions liable to cause excessive rises of pressure. Prof. Hopkinson's experiments consisted of taking a number of readings of the current flowing in a low resistance circuit connected across a large storage battery of 260 cells; automatic circuit-breakers, of the carbon contact type and the magnetic blow-out type, being connected in series with the circuit to interrupt the heavy flow of current due to the short circuit. The current readings were taken, by an ingenious apparatus clearly described in the

[1] See *Proc. Inst. Civil Engineers*, vol. cli. p. 353.

paper, at the moment the 'short' was applied, and at various short intervals of time after, until the flow of current was interrupted by the circuit-breaker. Prof. Hopkinson found that when using a carbon contact circuit-breaker set to release at 225 amperes the current rose to and was maintained at 3600 amperes during ·018 second, and gradually fell to zero in about ·06 second. With a magnetic blow-out circuit-breaker set to release at 300 amperes the current rose to and was maintained at 3500 for ·036 second, and fell to zero in about ·05 second.

The results of these experiments are plotted in fig. 34. It will be seen that the rate of change is very much greater in the magnetic blow-out type than in the carbon break type, and as a consequence the inductive

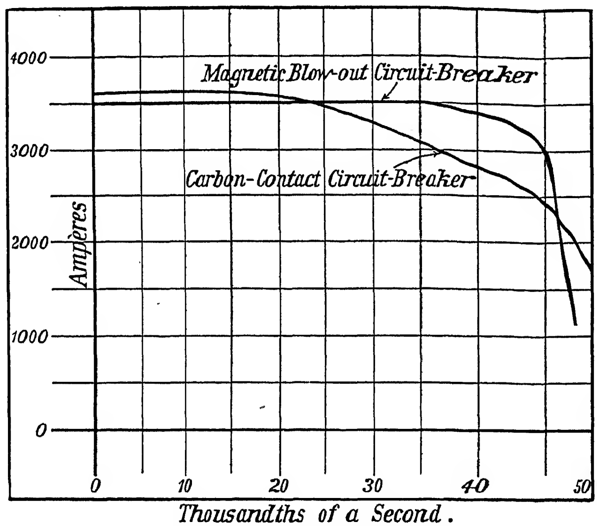


FIG. 34.—Curve showing suddenness of interruption due to magnetic blow-out.

rise of pressure due to this rapid change of current strength will be considerably greater in the first case than in the second. Prof. Hopkinson deduces from his experiments that the rise of pressure due to opening a short circuit current by means of the carbon break circuit-breaker under given conditions would amount to 300 volts—whereas the opening of a similar circuit by means of a magnetic blow-out circuit-breaker under the same conditions would cause a rise of pressure amounting to 1900 volts.

Circuit-breakers may be divided into three classes: (1) mechanical circuit-breakers operated by hand only, (2) mechanical circuit-breakers operated automatically in the event of an excess current, (3) fusible circuit-breakers.

The first-mentioned are seldom opened under full load, though provision

should, of course, be made for operating them under these conditions in case of emergency. The second and third classes are operated by a current considerably in excess of the normal load. They are, therefore, required to interrupt the circuit under much more trying conditions than the hand-operated circuit-breakers. The third class present the greatest difficulties, inasmuch as the blowing of a fuse is liable to liberate very much more metallic vapour, and consequently a much better conducting medium is provided.

Reference has been made to the fact that high-tension currents are more difficult to break than currents at comparatively low pressures. The difficulties are also greater if the current to be interrupted is a very heavy one. It is perhaps rather a question of horse-power than actual pressure or current alone. A direct current circuit is at all times much more difficult to interrupt than an alternating current circuit of the same kilo-watt capacity, and a highly inductive direct current circuit is the most difficult of all. The sudden opening of a field magnet circuit of a large generator will produce a very long and persistent arc, unless proper precautions are taken to prevent its formation, and if this arc is suddenly quenched by mechanical or other means, a pressure many times the normal working pressure will be induced across the terminals of the field, owing to the sudden withdrawal of lines of force from this circuit, and this, if permitted to occur, is very liable to break down the insulation of the field windings.[1]

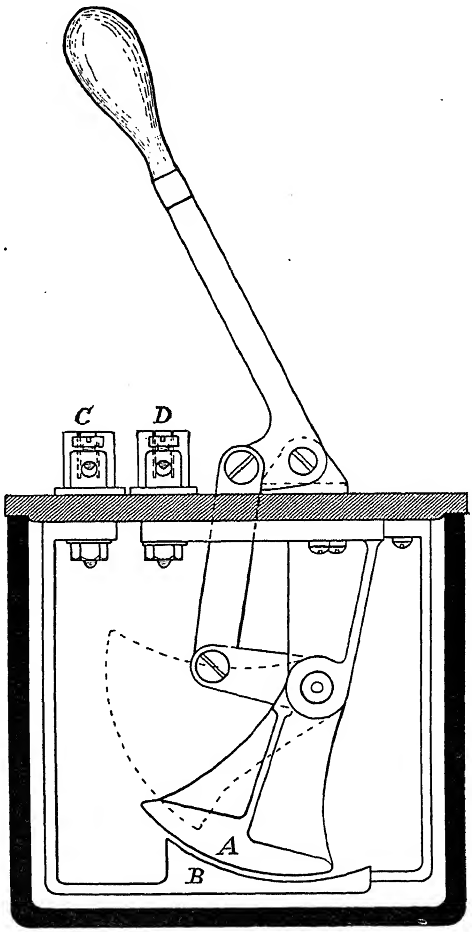

FIG. 35.—Brush liquid break field switch.

Special circuit-breakers have been designed to prevent this abnormal

[1] See reference to danger of suddenly interrupting an H.T. circuit (Chapter X.).

rise of pressure. The practice at one time was to greatly reduce the current in the magnetising circuit by gradually increasing the resistance of the circuit before finally breaking it. A device for this purpose is illustrated in fig. 35. The circuit-breaker was shunted by a pair of lead plates A B immersed in an earthenware vessel containing acidulated water. The action of opening the connection between the main contacts C D gradually increased the distance between the lead plates, and the circuit was finally broken when the moving lead plate was entirely withdrawn from the acidulated water. This device served its purpose so long as it

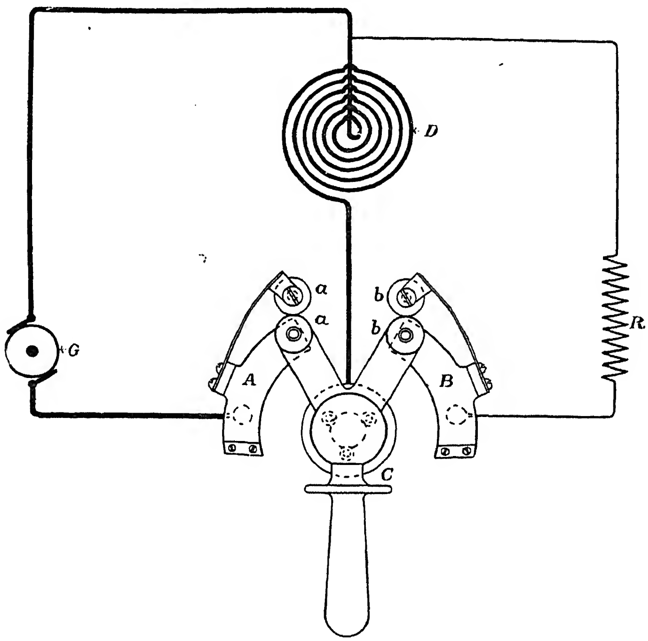


FIG. 36.—Diagram of connections of Siemens field switch.

was confined to use on comparatively small generators, though even then it required a certain amount of care on the part of the operator, as the rise of pressure would obviously not be prevented if the resistance was cut out too quickly.

A common practice at the present time is to shunt the field windings with a resistance just before the magnetising current is interrupted. The effect of this is to dissipate the energy stored in the field by the circulation of a moderately large current through the short-circuited winding. The direction of this induced current is, of course, such as to tend to maintain the magnetism of the field; as a consequence, a field so short circuited takes a considerable time to become thoroughly demagnetised.

A switch largely used for this purpose is the Siemens field switch, illustrated in fig. 36.

To close the field circuit D the movable switch arm C is placed to make contact with A only, B being open circuited. To open the field circuit the switch is moved over to B. Its construction is, however, such that it makes contact with B before it breaks with A. When fully opened the resistance R connected to B is left across the field. The field winding is in consequence under no condition open circuited. It will be evident, however, that, when the switch is passing through the position in which it is shown in fig. 36, the generator G has to provide the current taken by the resistance in addition to the field current, and it is this combined current which has to be broken by the switch on its leaving A. To limit

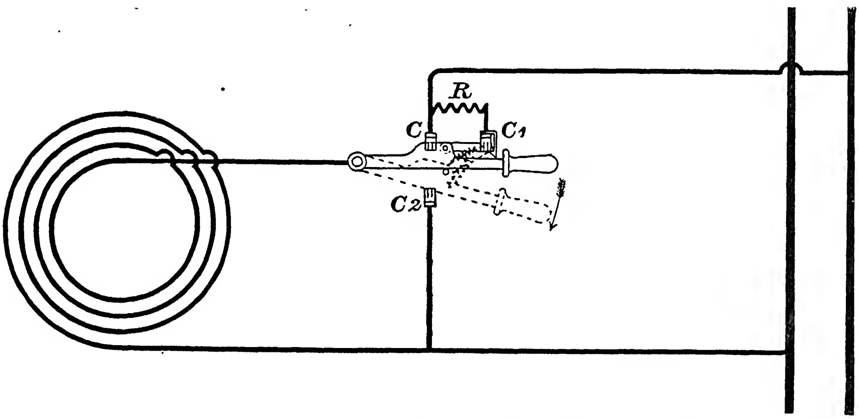


FIG. 37.—Diagram of connections of Cowan-Still field switch.

the arcing resulting from this break, the switch is provided with carbon roller contacts *a a*, *b b*.

In the Cowan-Still switch, illustrated diagrammatically in fig. 37, the formation of an arc, and consequently rises of pressure, are entirely prevented.

To open the field switch the handle is moved in the direction indicated by the arrow. This movement withdraws the main switch blade from the contact C; it does not, however, break the circuit, as the supply is still maintained through the resistance R, the contact $C^1$, and auxiliary blade. This latter blade is retained in contact with $C^1$ until contact is made between the main blade and $C^2$. In this position the exciter or field 'bus bars are for the moment short circuited by the switch; as, however, the resistance of R is equal to the resistance of the field winding, an excessive current is prevented from passing. The action of pushing the main blade home withdraws the auxiliary blade from $C^1$, thereby cutting off the supply. As, however, the field has already

been short circuited, the only arc formed on breaking the circuit is that due to interrupting the current through the non-inductive resistance R.

The advantages of this arrangement appear to be :—

(1) That the non-inductive resistance is inserted in series with the field instead of in parallel when the switch is opened, and consequently the demand upon the exciter is halved instead of doubled.

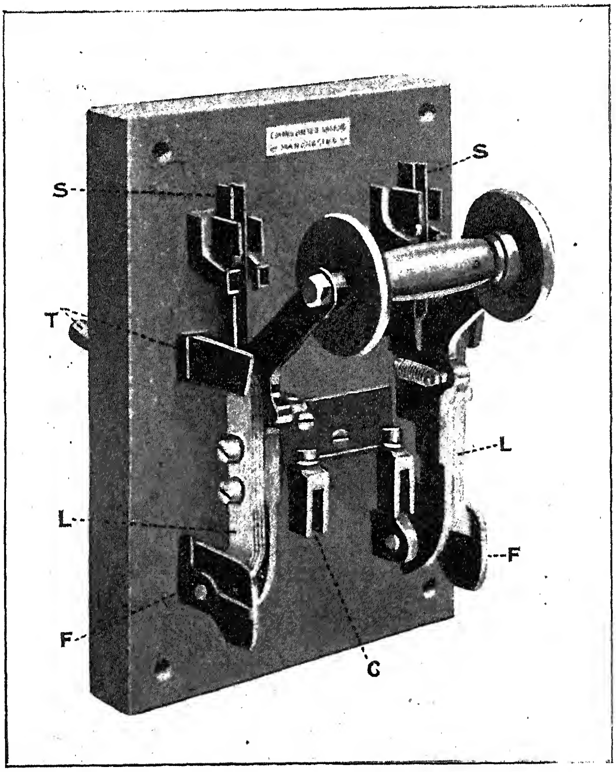


Fig. 38.—Photo of Cowan-Still double-pole field switch.

(2) The field is directly short circuited by the switch contacts without resistance in series with it, and as a consequence it dies down much more slowly.

In practice a double-pole switch is generally used. Such a switch is illustrated in perspective in fig. 38, and diagrammatically in fig. 39.

**Quick Break Hand Circuit-breakers.**—Of the various methods of breaking a circuit referred to in the early part of this chapter, one of the simplest is that of rapid separation of the contacts. A simple circuit-

breaker of this type for low-pressure work is shown in fig. 40. In this a divided flat blade is employed to connect the pair of contacts forming the two ends of the circuit to be completed. On making contact they act as one blade, but on breaking the friction of the contacts retains one half of the blade until the tension on the spring is sufficient to overcome the friction of the contact, when it flies off with great rapidity, thus interrupting the circuit without any appreciable arc.

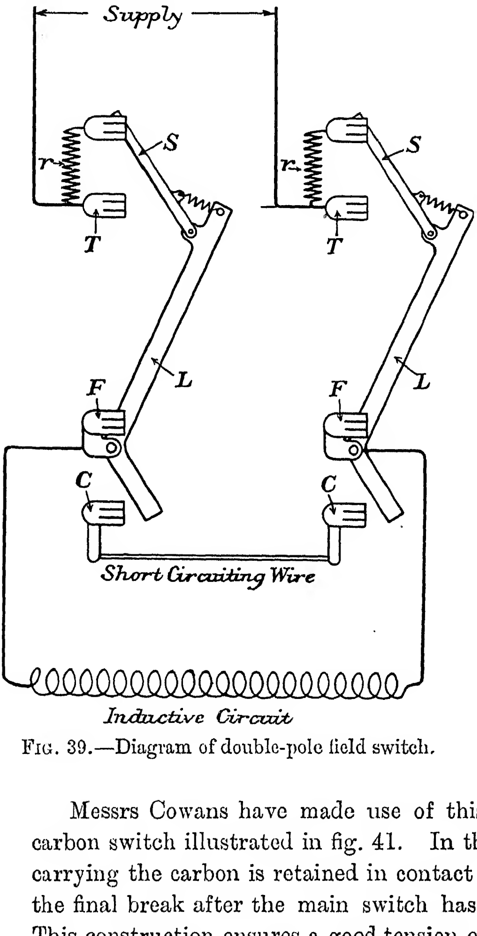


FIG. 39.—Diagram of double-pole field switch.

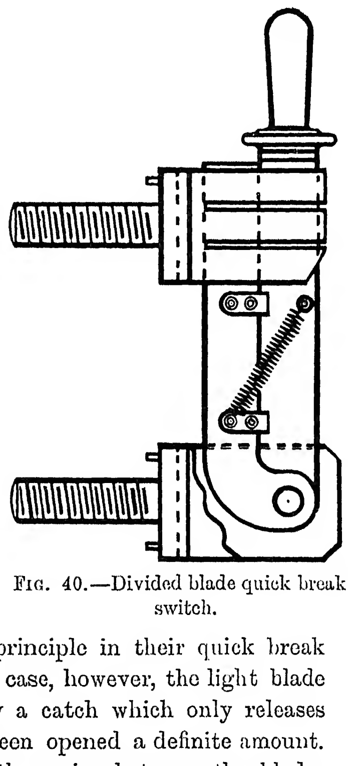

FIG. 40.—Divided blade quick break switch.

Messrs Cowans have made use of this principle in their quick break carbon switch illustrated in fig. 41. In this case, however, the light blade carrying the carbon is retained in contact by a catch which only releases the final break after the main switch has been opened a definite amount. This construction ensures a good tension on the spring between the blades at the moment the circuit is opened.

An example of a quick break high-tension circuit-breaker is the well-known Mordey trigger switch; this is illustrated in fig. 42. A powerful spring encircling the fulcrum tends to open the switch, but is prevented from doing so by a catch on the top of the fixed contact engaging with the

top of the movable contact arm. A second spring encircling the fulcrum of the catch tends to keep it securely locked. To open the circuit-breaker the catch is released by means of a cat-gut string, and in case the tension of the spring is insufficient to overcome the friction of the contact, a tail-piece attached to the catch positively forces the movable contact arm out of the fixed contact. This circuit-breaker is quite satisfactory so long as its use

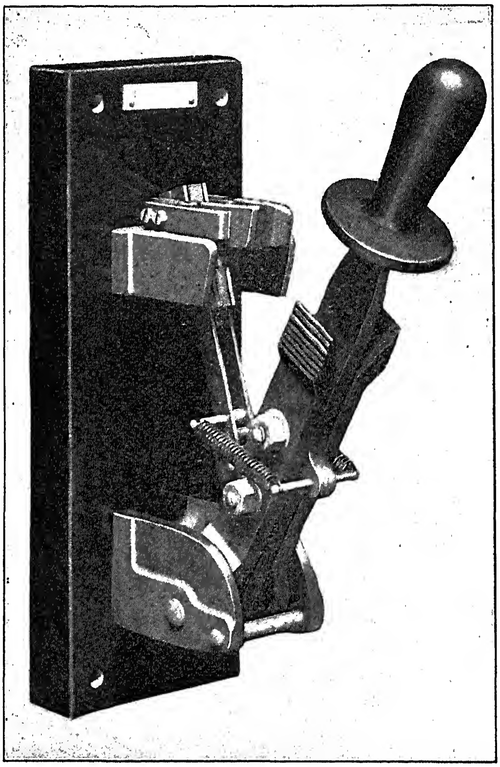

FIG. 41.—Hamlyn carbon break switch.

is confined to dealing with currents not exceeding about 10 amperes at a pressure of 2000 volts.

A form of circuit-breaker largely used in the States is the Westinghouse long quick break circuit-breaker, illustrated in fig. 43. One of the terminals of the circuit to be connected is supported from the top of a large marble panel, the movable contact being carried at the end of a long hollow arm made of insulating material. The flexible connection to this moving contact is carried through the centre of the insulating arm. The circuit-breaker is closed against the tension of powerful springs by

means of a handle connected to the movable arm through a second insulating link. It is held closed by a catch which, when released, allows the movable contact to fly away from the fixed contact with great rapidity. The final break is made between blocks of carbon supported from the upper

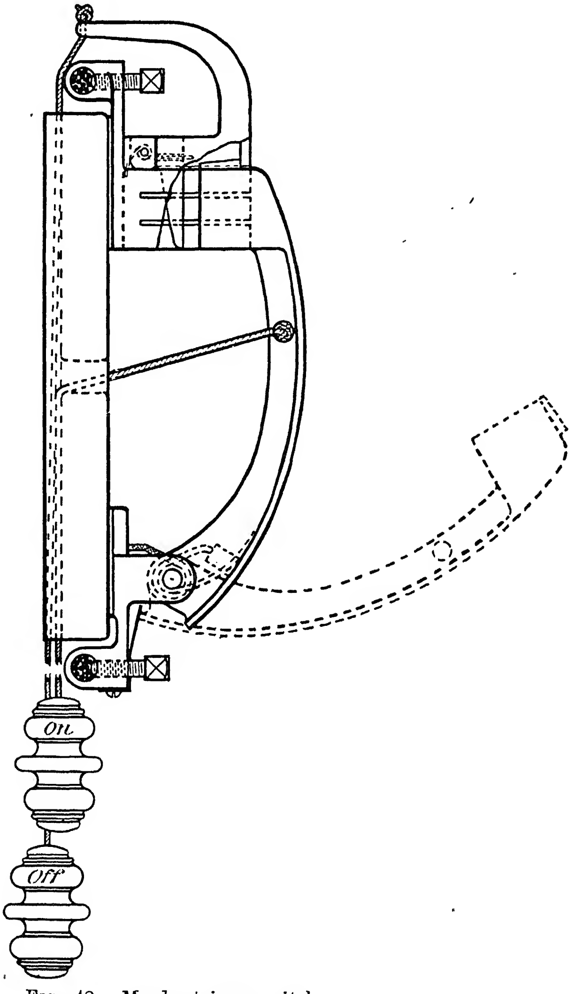


FIG. 42.—Mordey trigger switch.

parts of the metallic contacts. These circuit-breakers are usually constructed to be opened automatically, in the event of an abnormal current, by a magnetic device. The illustration shows three of these switches for a three-phase circuit, mechanically connected, so that they can be operated by one handle. Large marble shields are fixed between the circuit-breakers

on their respective phases to prevent the arc, formed on opening, jumping from the contacts of one phase to those of either of the adjacent phases.

An interesting form of quick break circuit-breaker is used in the high-

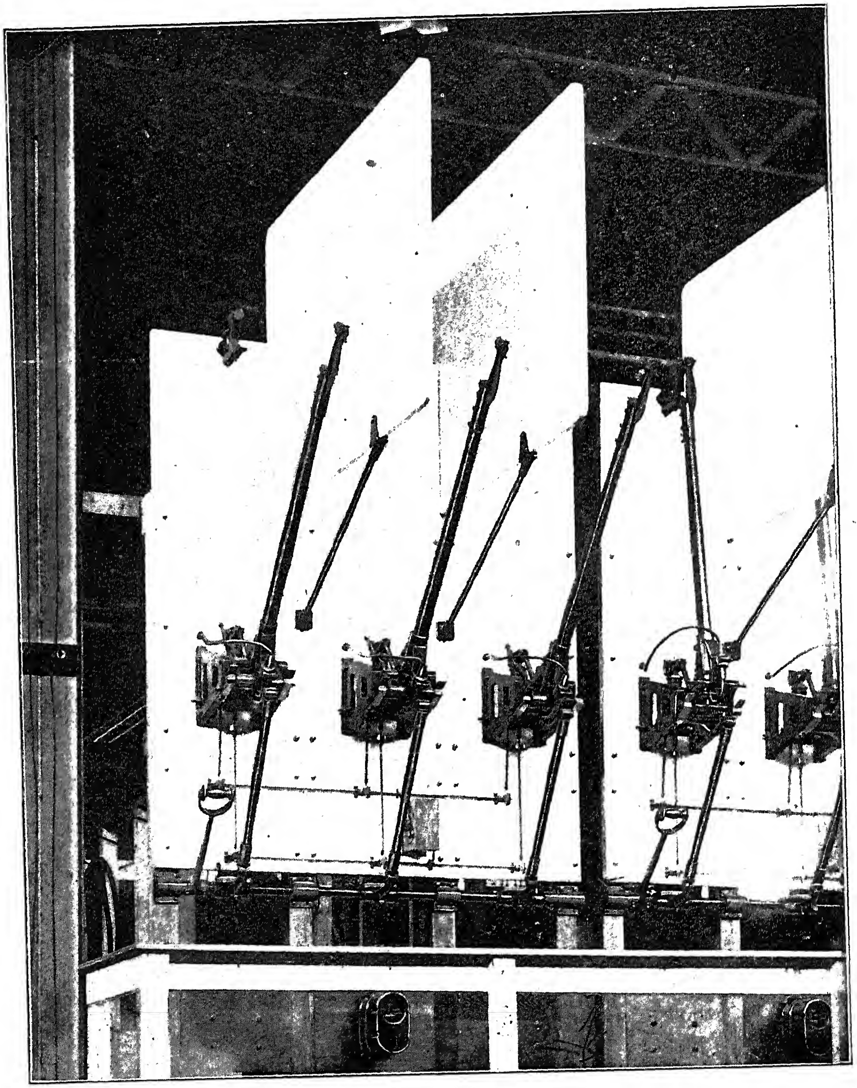

FIG. 43.—Westinghouse long break switch.

tension generating station at Berlin. The rate at which the contacts are here separated is increased fourfold by employing four movable contact arms instead of one. These arms are all mechanically connected, and may

therefore be opened or closed simultaneously by the movement of one handle. The contacts on two of these arms are electrically connected to the terminals of the circuit to be completed or broken, the opposing two contacts being merely electrically connected together. An insulating partition is placed between the pairs of contacts (see C, fig. 144).

**Water Break Circuit-breakers.**—The Raworth circuit-breaker, illustrated in fig. 44, is an example of this type. The contacts connected to the respective circuits to be interrupted are mounted on a suitable insulator and covered by water contained in glass cylinders. These contacts are connected together by means of two interconnected plungers supported from a cross beam. Small pistons attached to these plunger rods, working in a cylinder above the water pots, serve to guide the connecting plungers into the contacts. The cylinders are made watertight by rubber joints between the glass and metal support. This form of circuit-breaker has been repeatedly used for breaking very heavy currents with only a few inches of water over the contacts, and so long as this condition is maintained, it may be relied upon to safely open the circuit. The drawback to its use is that the glass cylinders are liable to crack or the joints to give out, and thus allow the water to leak; and any possibility of water leaking in the neighbourhood of high-tension connections should, of course, be avoided.

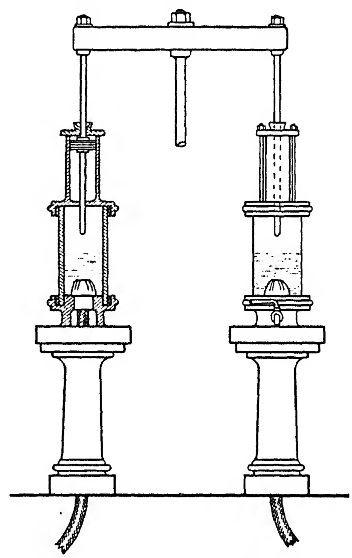

FIG. 44.—Raworth water break switch.

An improved form of water break is the Cowan circuit-breaker (see fig. 134). Metal water pots are here used, the pots being cast in one piece, with a terminal projecting from the bottom. A small glass window is fixed in the front of the pot to enable the attendant to see the height of the water. The movable contact arm in this design has a radial movement, and when the circuit is opened this contact is lifted quite clear of the water pot. One water pot only is provided for each circuit; it is thus a single break switch only. The current is conducted to the movable contact from the 'bus bar by means of a flexible connection. When the switch is open the water pot connection is dead, and the height of the water may, therefore, be adjusted or the contact cleaned without any great risk to the attendant.

The Brush Co.'s latest standard water break switch (see fig. 139) is very similar to the one last described, the chief difference being that two

water pots are used for each circuit, and the movable contact is merely a ⊓ shaped piece for connecting the two pots together. The movable contact in this case is made dead by opening the switch, but one of the water pots is always alive, unless some additional switch is provided for disconnecting it from the 'bus bars.

The author has also used a double pot water break switch (see fig. 138), but in this case the water pot connected to the 'bus bar is made dead when the switch is opened by placing the three-way 'bus bar switch in a position half-way between the two 'bus bar contacts.

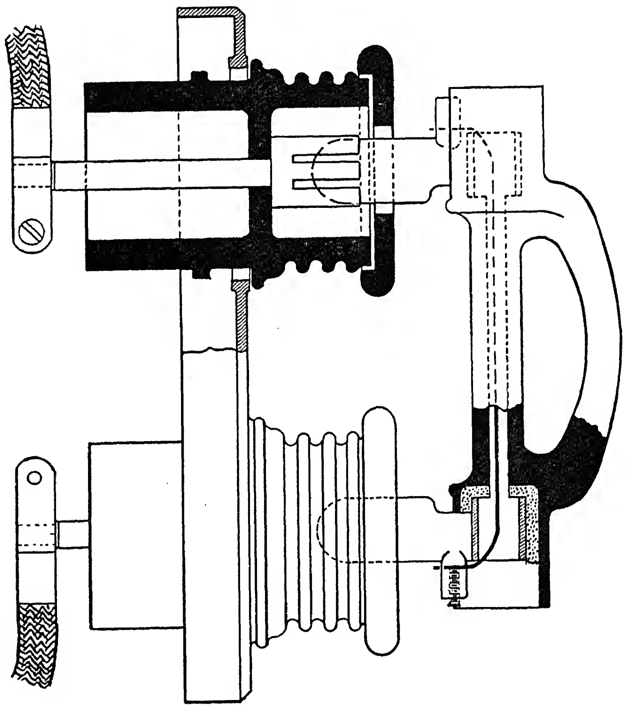

Fig. 45.—Bates fuse.

**Blow-out Circuit-breakers.**—A method of interrupting the arc that has been largely used by different designers is that of blowing it out by a blast of air. The Fowler circuit-breaker is an interesting example of this type of break. The action of opening the switch forces a piston into a cylinder, and the air thus compressed is directed to impinge upon the arc and thus blow it out.

The well-known Bates fuse (fig. 45) is another example of a blow-out circuit-breaker. The fuse wire is carried through a porcelain tube, which also forms the carrier for the fuse contacts. When the fuse melts, due to an abnormal rise of current, the fuse wire parts midway between the

contacts. The intense heat, due to the arc formed immediately the metallic circuit is broken, causes a rapid expansion of air, which escapes at each end of the tube, and in doing so blows out the arc. When this fuse was first introduced it was found that the first time a new fuse carrier was used it invariably broke the circuit satisfactorily, but on attempting to use a fuse carrier a second time the arc was often maintained. This difficulty was traced to be due to a thin film of copper deposited on the

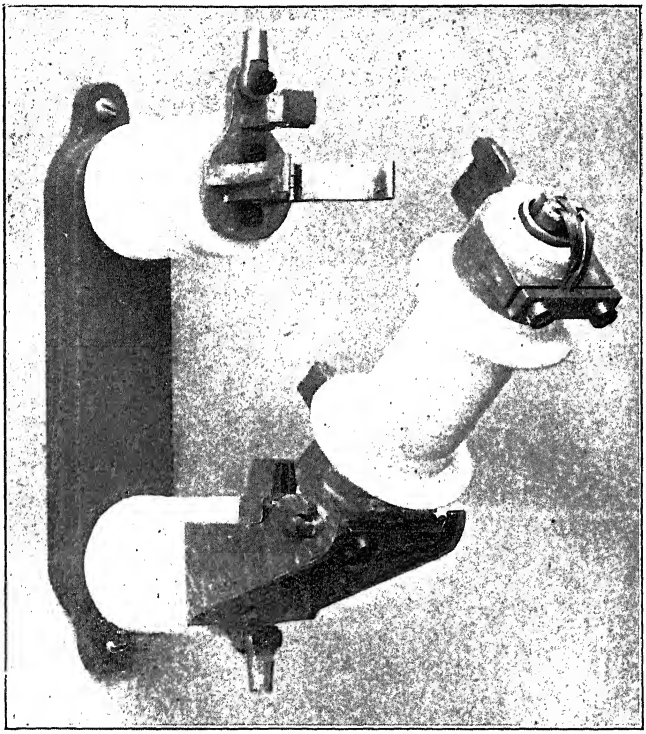

FIG. 46.—Schuckert fuse.

interior of the tube by the blowing of the first fuse. It appeared that the arc was broken by the blow-out action, but the circuit was re-established through the copper film deposited on the tube. To overcome this difficulty the makers now provide a replaceable pipeclay tube to surround the fuse wire, and the interior of the handle is thus protected from the copper deposit. To ensure the satisfactory operation of these fuses it is very necessary to see that an inner tube is never used a second time.

A modified form of Bates fuse is the British Schuckert Co.'s fuse, illustrated in fig. 46. The fuse wire is in this case divided into a number

of strands, each strand being carried through a separate tube. It has been found that a fuse divided in this way is very much more reliable for heavy currents. An explanation which is given for this increased reliability is that the difficulty of interrupting an arc is very greatly increased

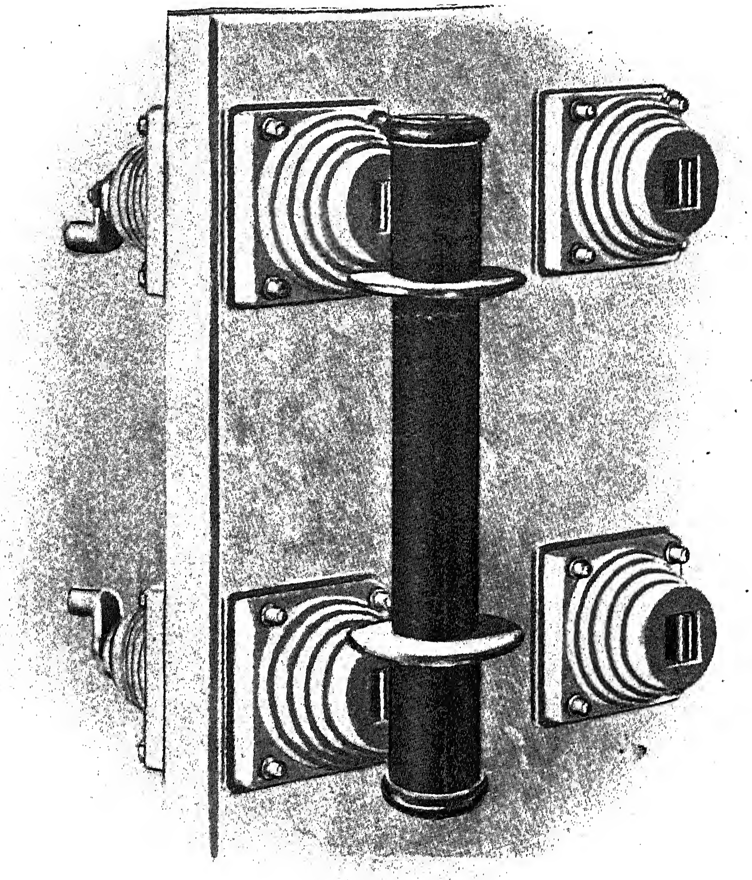

FIG. 47.—Stanley fuse in contacts.

by the amount of metal that is vaporised; and by dividing a large fuse into what is actually a number of small fuses this difficulty becomes greatly reduced, owing to the fact that the circuit is probably finally broken in one only of the sections. The illustration shows a fuse designed for 60 amperes at 5000 volts. This fuse carrier is provided with a hinge

to enable it to be conveniently used as a switch, though it must not, of course, be so used when there is any appreciable current flowing through it. A carbon contact is provided to avoid any pitting of the main contacts when opened with current flowing.

An interesting form of blow-out circuit-breaker is the Stanley ball fuse,

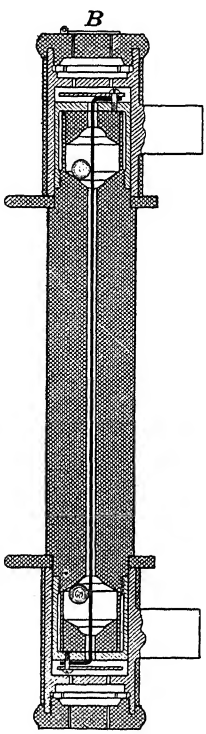


FIG. 48.—Section of Stanley ball fuse.

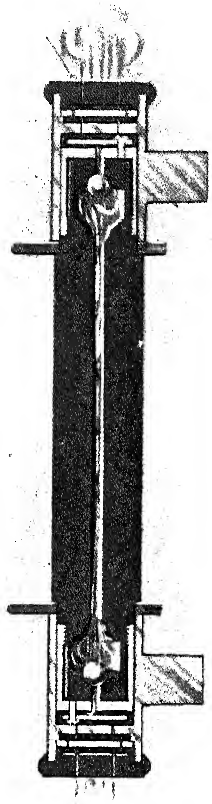

FIG. 49.—Stanley fuse blowing.

illustrated in figs. 47, 48, and 49. This fuse consists of an ebonite barrel about $1\frac{1}{2}$ inches in diameter. This barrel is bored with a $\frac{3}{16}$-inch hole through its centre. A chamber is provided at each end of the tube large enough to contain a small carbon ball, which is normally held at one side of the chamber by the fuse wire. A metal cap is screwed over each end of the ebonite barrel, and the fuse wire is clamped to this metal cap under

an eccentric washer. Outer metal caps from which the contact tongues project fit tightly over the caps first mentioned. The latter caps are perforated at the ends with a number of small holes through which the gases escape. A small aluminium tell-tale vane B rests on the top of these perforations, and the escaping gases, incident to the blowing of the fuse, throw this little vane over into view of the attendant, thus indicating that the fuse has blown. The effect of blowing the fuse is illustrated in fig. 49. The fuse wire becomes volatilised, and the escaping gases blow the carbon balls into the cavities, effectively cutting off the arc. It will be seen that, quite apart from the action of the ball valves, the gases are not permitted to blow straight through to atmosphere, as they have to first pass under the clamping washer and through the perforations. This path is so devious that by the time the vapours reach the atmosphere they are quite harmless and non-luminous. This fuse has been designed, and is largely used in the States, for working pressures up to 30,000 volts. It is interesting to note that, in spite of the fact that no molten copper is allowed to blow directly out at the ends of the fuse, as in the case of the Bates fuse, no copper deposit appears to be left in the tube. In fact, after the fuse has been blown several times there is nothing beyond a slight deposit of soot on the metal caps at the end of the tube to show that the fuse carrier has ever been used. Fig. 47 is a perspective view of one of these fuses mounted on a marble base. It will be seen that the whole of the metal parts are thoroughly enclosed, thus rendering the fuse carrier perfectly safe to handle when the circuit to which it is connected is alive. The barrel can be re-fused, after blowing, in a very short time.

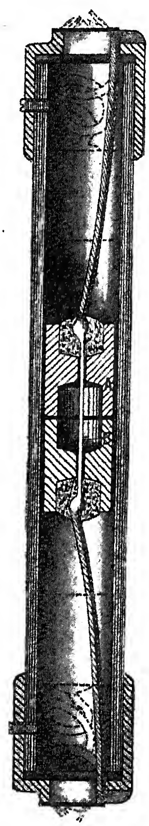

Fig. 50.—Section of Dale fuse.

The Dale fuse, made by Messrs Cowans, and illustrated in fig. 50, is another interesting and reliable type of blow-out circuit-breaker. The chief feature of this device is the very small amount of fuse wire used. Reference has previously been made to the fact that the difficulty of interrupting an arc is in a great measure due to the metallic vapour. In a long fuse much more metal is vaporised than in a short fuse. The fuse wire in the Dale fusible circuit-breaker is only about half an inch long; the ends of this are, however, attached to small porcelain pistons A B fitting moderately tightly in an ebonite or vulcanised fibre cylinder. Contact is made between the fuse wire attached to these porcelain pistons and the terminal caps at the

end of the tube by means of very flexible conductors. The gases formed by the melting of the fuse force these pistons up the tube, the flexible connections allowing this movement. By this means the arcing distance is greatly increased, and the arc thereby becomes effectively extinguished. The diameter of the cylinder is increased at the end remote from the fuse, thus allowing the gases to escape between the piston and the walls of the cylinder at this end. The author has tried the experiment of connecting a number of these fuses of different sizes directly across the poles of a

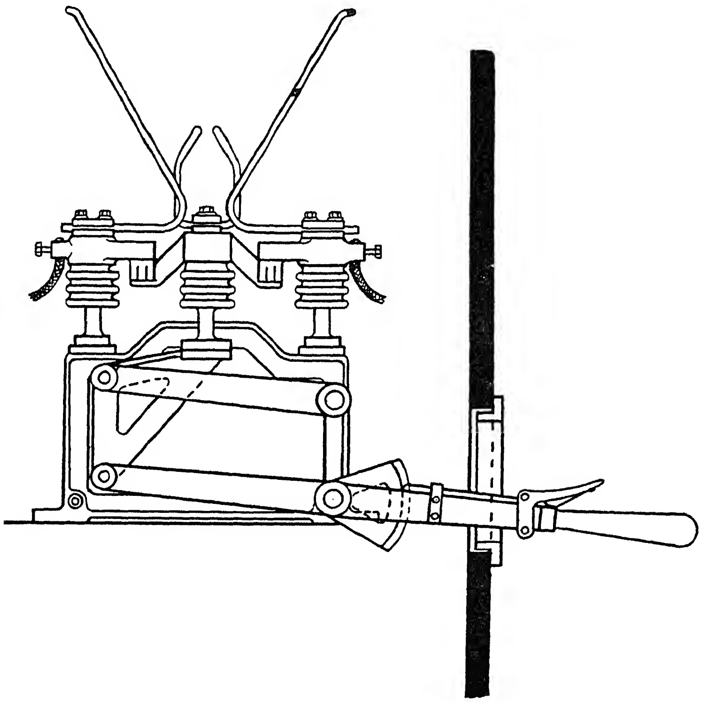

FIG. 51.—Schuckert horn break switch.

200 K.W., 2000 volt, Mordey alternator. On every occasion the circuit was instantly interrupted without the slightest sign of visible arc.

**Magnetic Blow-out Circuit-breakers.**—It is well known that a powerful magnet placed in close proximity to a continuous current electric arc will repel the arc with considerable force. This principle has been employed by the British Thomson-Houston Co. in their standard circuit-breakers, and by other makers.

**Horn Break Circuit-breakers.**—This type of circuit-breaker is very largely used on the Continent for both switches and fuses. Fig. 51 illustrates the British Schuckert Co.'s circuit-breaker made on this principle. Curved metal horns project vertically from the contact plungers, each

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horn consisting of two pieces of $\frac{1}{4}$-inch rod placed side by side and connected together at the top. Contact is made at the lower extremity of these horns by a wedge-shaped plunger fitting between the horns. The main current is carried by a blade making connection with two knife contacts. To open the circuit the connecting blade is withdrawn vertically downwards by the link motion operated by the controlling handle. After the circuit is broken at the main contacts it is maintained between the horns by the wedge-shaped plunger. When the latter is withdrawn an arc is started between the lower extremities of the horns, and this runs upwards, rapidly increasing in length until it exceeds the distance at which the pressure is capable of maintaining an arc.

The makers claim to have constructed circuit-breakers on this principle capable of breaking with perfect success 100 amperes at 20,000 volts. This circuit-breaker is so arranged that it can be fixed at the top of a switchboard and operated by a lever fixed in a convenient position on the front of the board.

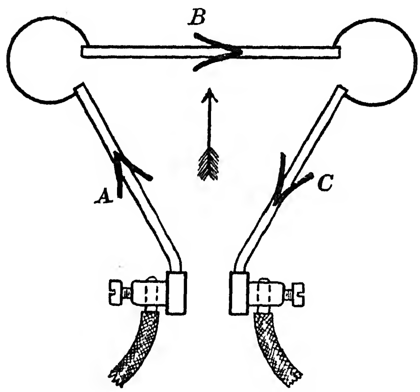



FIG. 52.—Diagram illustrating theory of horn break blow-out.

Circuit-breakers of this type are also largely used for interrupting the arc formed on blowing a fuse. The fuse wire is, in this case, connected across the lower extremities of the horns, and the arc established by the melting of the fuse is carried up the horns in the same manner as in the mechanical circuit-breaker referred to above.

It is often thought that the action of this circuit-breaker is due to the arc being carried up high by the upward draught of air resulting from the rise of temperature due to the arc. Although the upward draught of air probably does assist the action of the arc, it has been found that this does not entirely account for it, as a circuit-breaker of this type laid over on its side will repel the arc to the further extremities of the horns almost as well as with the horns in the vertical position shown. The effect appears to be chiefly due to magnetic repulsion. It is well known that if a heavy current is caused to flow in opposite directions through two adjacent conductors, the conductors tend to repel each other. The Siemens dynamometer is based upon this principle. If three conductors A, B, and C, fig. 52, are arranged in the form of a triangle, and the conductor B is left free to move in the direction indicated by the arrow, on sending a heavy current through the circuit, B will be repelled by both A and C, as

the direction of the current in B is opposite to that in A and C. It is evident that the shape of the conducting circuit, when the arc is, say, half-way up the horns, will be similar to that formed by the three conductors A, B, and C; the arc, being the conductor B, will be repelled by A and C further towards the extremities of A and C.

To ascertain to what extent the action of this circuit-breaker could be attributed to magnetic repulsion, the author carried out some time ago a number of experiments with different shapes of projecting horns. The

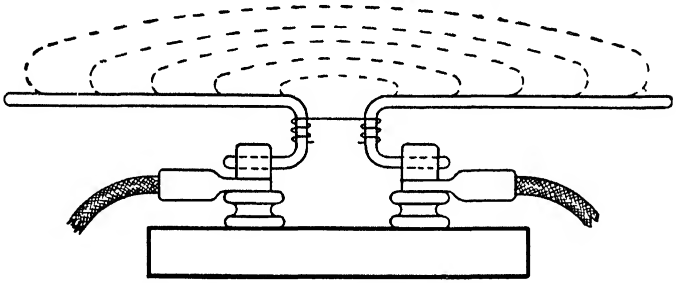


FIG. 53.—Flat horizontal horn break fuse.

length of fuse wire was in all cases 3 inches, and in all experiments a single strand of 16 copper wire was short circuited across the terminals of a 2000 volt, 200 K.W. Mordey alternator. It was found that a pair of horns projecting horizontally, as shown in fig. 53, interrupted the arc formed on blowing a fuse bridging the two horns with equal certainty and much greater rapidity than in the case of the horns arranged in the usual manner. The arc was repelled to the further extremities of the horns, and one can imagine the path of the arc would be as indicated by the dotted

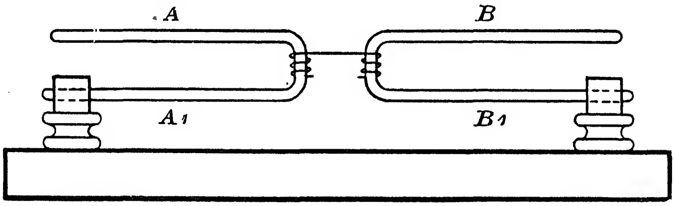



FIG. 54.—Action of flat horns neutralised.

line. It is evident that the upward draught of air has in this case nothing to do with the arc being repelled to the extremities of the horns. On the other hand, one would expect the effect of the magnetic repulsion to be very much more apparent in this case, as it evidently is.

Horns bent in the shape shown in fig. 54 absolutely failed to interrupt the circuit. It is obvious that in this case the current in $A^1$ and $B^1$ neutralises the effect of the current in A and B.

Horns arranged as shown in fig. 55 operated perfectly. A photograph

taken of the arc formed by this arrangement of the horns is reproduced in fig. 56.

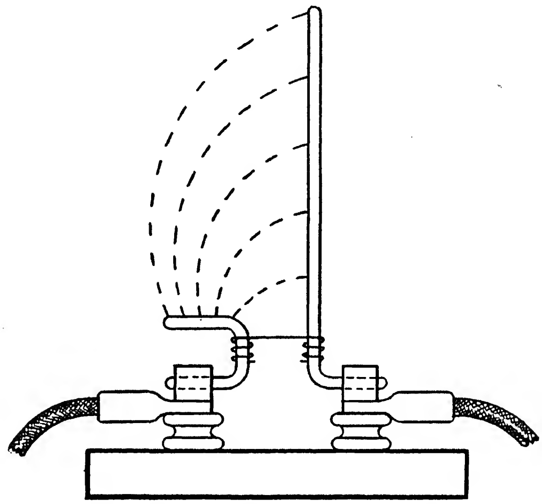


FIG. 55.—Long and short horn break fuse.

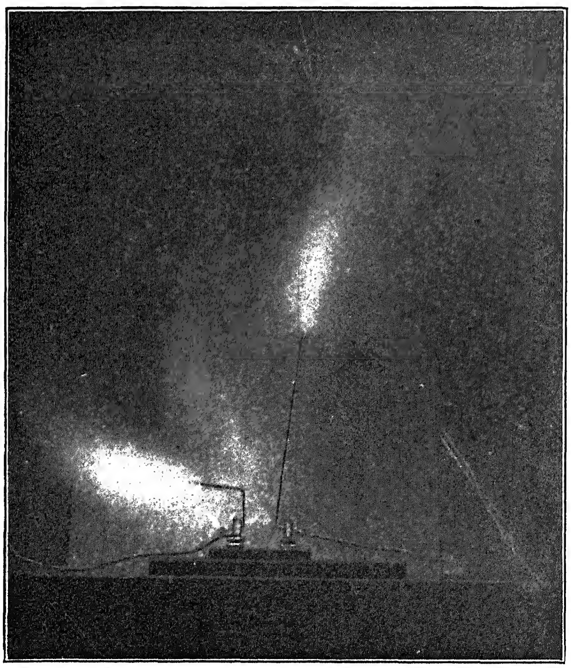


FIG. 56.—Photo of arc caused by long and short horns.

It would seem from the photographs that the arc is repelled with considerable force from the extremity of the short horn. There appeared, in fact, to be quite a blow-pipe action from this horn. To ascertain to what extent this was so, the experiment was repeated with the horns thoroughly enclosed in a chimney built of fire-bricks, about 3 inches clearance being allowed between the horns and the interior of the chimney. It was found on removing the bricks after the fuse had blown that the arc repelled from the extremity of the short horn had burned a hole about a quarter of an inch deep in the brick upon which it had impinged. The bricks directly above the burnt brick were slightly

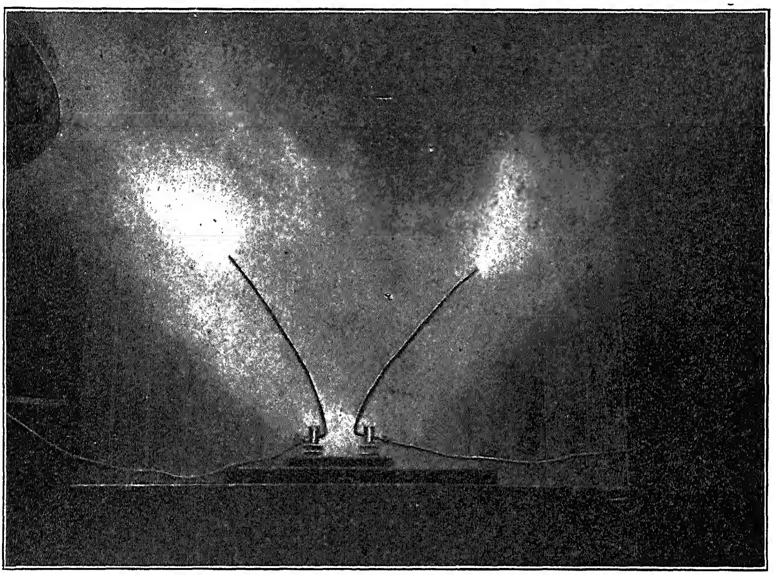


FIG. 57.—Photo of arc due to horns of usual shape.

blackened, but those on the opposite side of the vertical horn were barely marked. The arc was not instantly extinguished, as in the open type horn fuse, but was repeatedly re-established for several seconds, each time with a very loud report. Apparently it was repelled to the extremity of the short horn, and was then reflected back by the brickwork, and thus re-established.

Fig. 57 is a reproduction of a photograph of the blowing of a fuse across horns of the usual shape. It will be seen that the arc is instantly carried to the top of the horns, and is there maintained for an appreciable time—long enough, in fact, to burn away a considerable portion of the horn each time the fuse is blown. There are no signs of the arc being broken and re-established as it travels up the horns, either in the photograph or from

the actual appearance of the horns. It is noticeable that the arc is fiercer on the outside of the horns than between them, thus again indicating the effect of repulsion.

Fig. 58 represents the blowing of a similar fuse across horns shaped as in fig. 53. Here the arc is obviously repelled to both extremities of the horns, but is not maintained there—at least the ends showed no sign of being burnt. The horns were, however, pitted along their entire length, clearly showing the path of the arc.

An interesting horn break fuse may be made by threading two ends of cable through a porcelain tube about 6 inches long, and merely twisting a

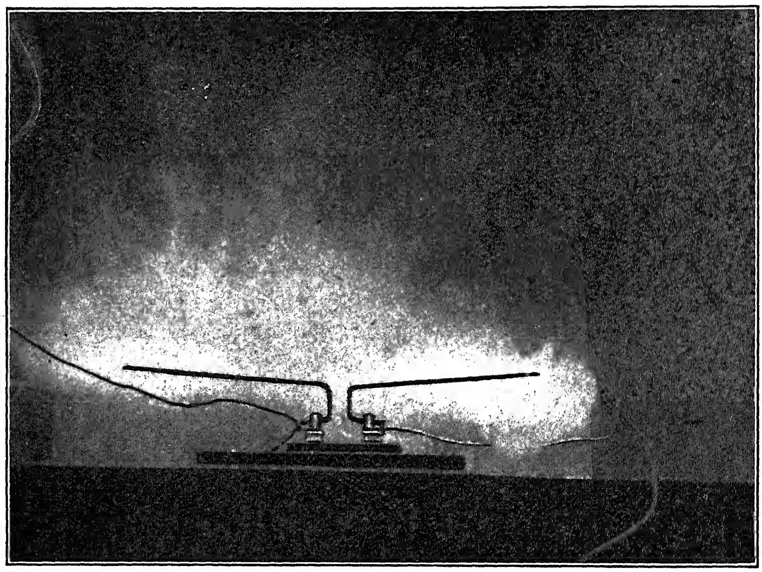


Fig. 58.—Photo of arc from flat horns.

piece of copper fuse wire across the projecting ends of the cable, as shown in fig. 59. The arc formed on blowing a 200-ampere, 2000-volt, fuse will be extinguished by the magnetic repulsion between the current flowing in the two cables and the arc. It will be evident that the direction of the current in the arc will be opposite to that of the current in the two cables.

The drawbacks to the use of all horn break circuit-breakers are that considerable space is required for safe operation, and that violent surgings are liable to be produced through the system whilst the arc is being maintained through the metallic vapour, causing abnormal, and often injurious, rises of pressure. It has been suggested that the maintenance of the arc across carbon points is not liable to be so injurious in this respect. The

author has designed and used for some considerable time a horn break circuit-breaker in which the arc is only maintained between carbon points. This circuit-breaker, which has been repeatedly used for carrying and breaking a circuit of 500 kilo-watts at 2000 volts, is illustrated in figs. 129 and 130.

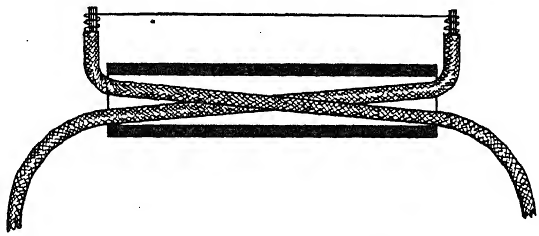


FIG. 59.—A simple horn break fuse.

When the circuit-breaker is closed the current is carried through the heavy laminated brush. This is shunted by a pair of carbon-tipped horns, and these are constructed to remain closed an appreciable time after the circuit has been broken at the main contacts. The arc is thus actually

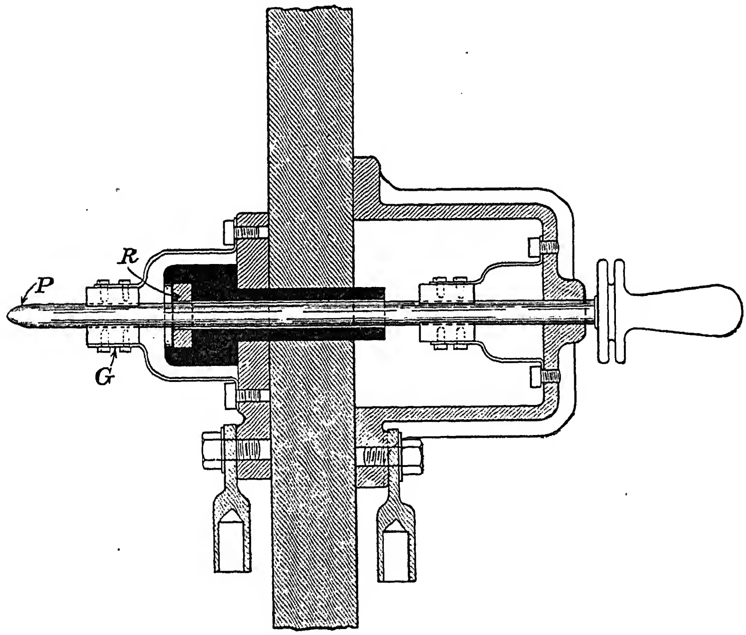



FIG. 60.—Siemens plunger switch.

started across the carbon tips, and these are drawn apart as the circuit-breaker is opened. The arc is repelled by the current flowing in the two carbon-tipped horns, the effect being practically similar to that shown in the fusible circuit-breaker illustrated in fig. 59. This circuit-breaker

has repeatedly broken 300 amperes at 2000 volts across a distance of less than 6 inches between the carbon points.

**Arc-cooled Circuit-breakers.**—In the Siemens circuit-breaker, illustrated in fig. 60, the arc is extinguished by withdrawing the connecting plunger P through a metal ring R fixed and supported in an insulating tube. When the plunger is withdrawn from the contacts G, which are electrically connected to one of the terminals of the circuit to be interrupted, an arc is started between the plunger and these contacts, and this is to some extent drawn into the tube, causing a great evolution of heat. The metal ring absorbs this heat, and so cools the arc and prevents it from being maintained.

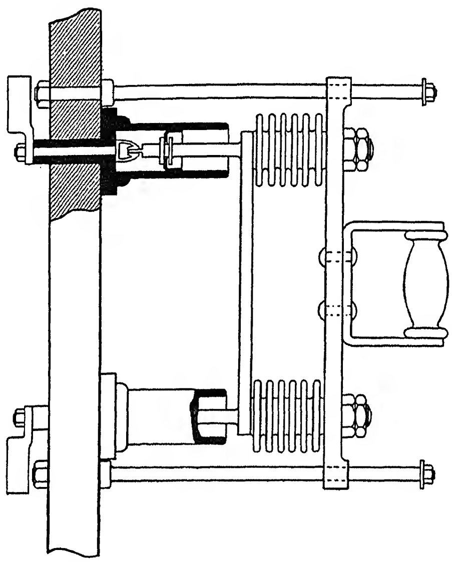


Fig. 61.—Partridge piston switch.

The metal ring also serves to prevent the arc from injuring the insulating tube.

Another method of cooling the arc formed on breaking the circuit is illustrated in fig. 61. This circuit-breaker, designed by Mr Partridge, consists of a pair of suitably guided, movable, electrically connected contacts provided with pistons adapted to slide, with a good fit, in porcelain cylinders containing the fixed contacts connected to the ends of the circuit to be completed. Upon withdrawing the movable contacts from the fixed contacts a partial vacuum is set up in the cylinders until the pistons leave the open ends, whereupon air enters the cylinders and destroys the partial vacuum therein. This sudden inrush of air is said to effectually extinguish any arc that may have been formed.

A very simple and effective method of cooling an arc is that employed

in the Partridge sparklet circuit-breaker, an example of which is illustrated in fig. 62. Ordinary sparklets A, such as are commonly used for making effervescing water, are supported by spring clips directly over the

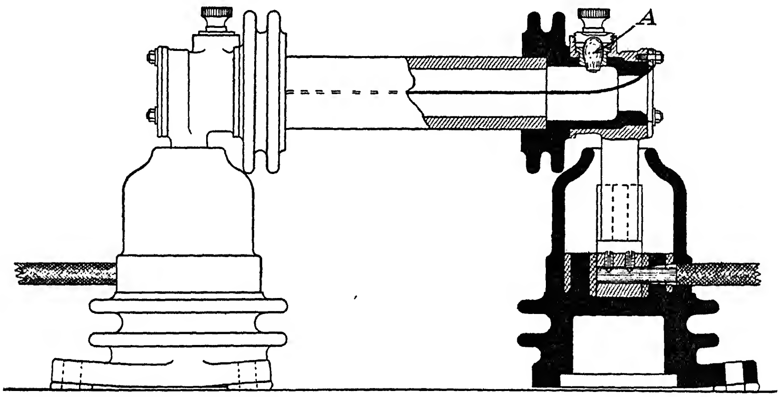



FIG. 62.—Partridge sparklet fuse.

point at which the circuit is to be broken. The arc formed fuses the metal cases of the sparklets, and allows the gas to escape. The rapid expansion of

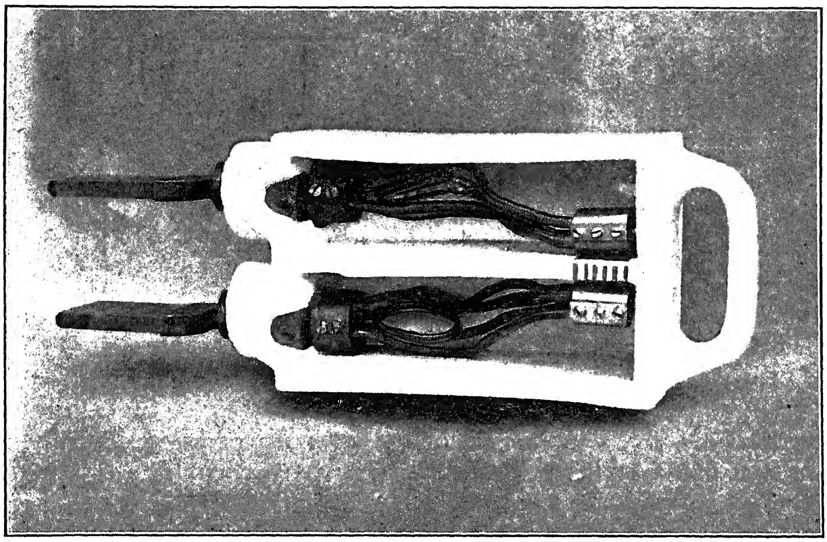


FIG. 63.—Ferranti oil break fuse.

the gas cools the surrounding air to such an extent that the maintenance of the arc is effectually prevented. From a number of experiments that have been made, it has been found that a sparklet circuit-breaker will effectually

interrupt a heavy current arc at a pressure of 10,000 volts with a very short break.

**Oil Break Circuit-breakers.**—One of the most successful methods of preventing the formation of an arc is that of breaking the circuit beneath the surface of an insulating oil. This method has been very largely applied in this country in the well-known Ferranti high-pressure fuse. This is shown in fig. 63. A rectangular porcelain vessel is divided into two compartments; each compartment contains a metal spring, to which the ends of the fuse wire are connected. These springs are held in tension by the fuse, resting on the top of the partition dividing the contacts. When the fuse wire melts the tension on the springs is released and the ends of the fuse wire are withdrawn beneath the surface of the oil. The arc formed is thus instantly extinguished. Metal tongues projecting from the ends of each of

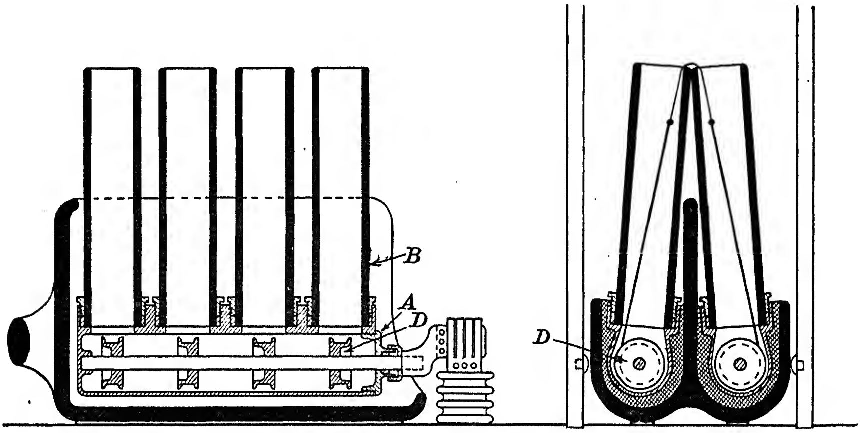



FIG. 64.—Ferranti E.H.T. oil break fuse.

the compartments are connected to the respective springs in the containing vessel; these tongues serve to connect the fuse to the terminals of the circuit to be completed.

A modified form of Ferranti oil break fuse specially designed for extra high pressure work is shown in section in fig. 64. This fuse might be described as a multiple oil break circuit-breaker, as the fuse wire, instead of consisting of one strand, is divided into a number of sections, each section being entirely separate from adjacent sections. The higher the pressure and current to be dealt with, the greater is the number of sections. A pair of gun-metal fittings A, provided with contact tongues, are cemented respectively into the two separated compartments of a porcelain carrier. These gun-metal castings are fitted with glands into which vertical porcelain tubes B are clamped. A spindle running longitudinally through each casting is fitted with revolving drums D, each drum having a clockwork

spring fitted to it. A flexible conductor is carried round the outside of each of the drums, and fuse wire is soldered and clamped on to this conductor. The porcelain tubes just touch one another at the top. The fuse wire bridges over the top of one tube to the tube directly opposite it.

Fig. 65 is a detailed section of Messrs Ferranti's standard oil break switch (see also fig. 131, Chapter VII.). The main circuit is completed through contact A, movable switch arm B, and contact C. This circuit is shunted by a second path $A^1$ $B^1$ $C^1$, arranged to be broken under

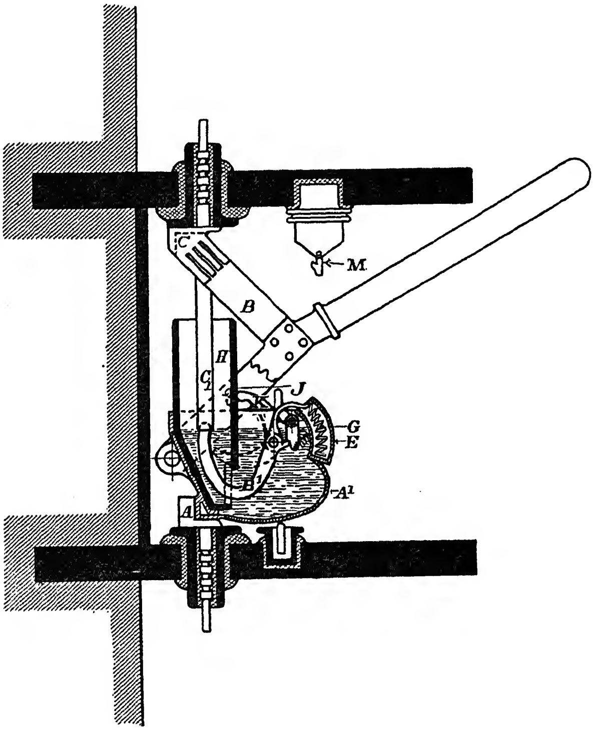



FIG. 65.—Ferranti oil break switch.

oil. A gun-metal tank $A^1$ is filled with oil to nearly touch the contact $C^1$. When the switch is opened the circuit is first broken at the dry break main contact C, the supply being still maintained through the shunt circuit $A^1$ $B^1$ $C^1$, which is held in the closed position by the catch E. Further movement of the switch handle releases this catch and allows the compression spring G to withdraw the arm $B^1$ from the contact $C^1$, thus rapidly drawing the arc beneath the surface of the oil. To prevent any liability of an arc being started between the contact $C^1$ and the tank $A^1$, $C^1$ is surrounded by a porcelain tube H securely cemented in the tank. In closing the switch the pin J engages in the arm K carried outside the oil tank on an extension

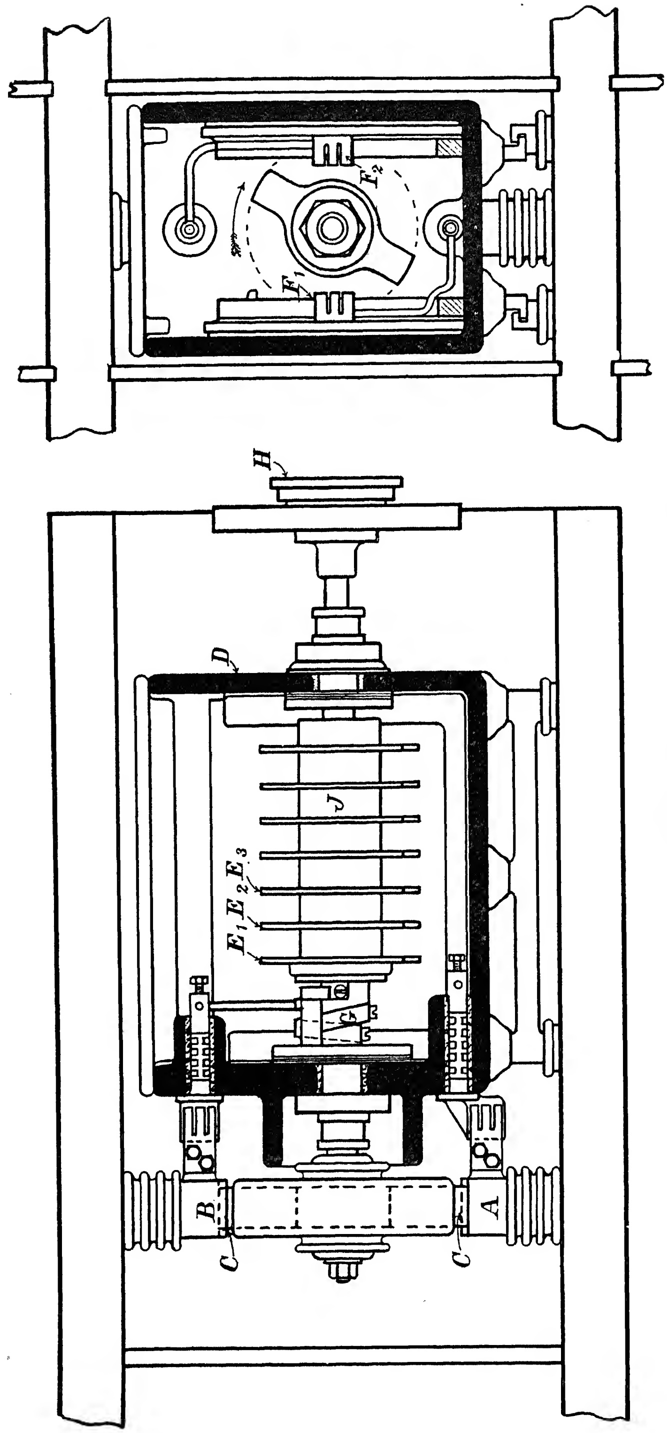



FIG. 66.—Ferranti E.H.T. multiple oil break switch.

of the shaft carrying the arm $B^1$, and lifts this until it makes contact with $C^1$, in which position it is held by the catch E.

Messrs Ferranti have also recently introduced a new oil break switch for controlling extra high tension circuits. This is shown in section in fig. 66. When the switch is closed the contacts A and B are directly short circuited through a flexible contact brush C, outside the oil-containing pot D. This circuit is, however, shunted by a number of blades $E^1$, $E^2$, $E^3$, and contacts $F^1$, $F^2$, entirely covered by oil inside the pot. The insulating barrel J is free to move about the main shaft, and is only attached to this shaft through the spring G. The switch is opened by turning the disc H forming the handle. As this is rigidly fixed to the shaft carrying the main contact brush, the circuit is first broken outside the pot. It is, however, maintained through the multiple contacts until the tension of the spring G is suffi-

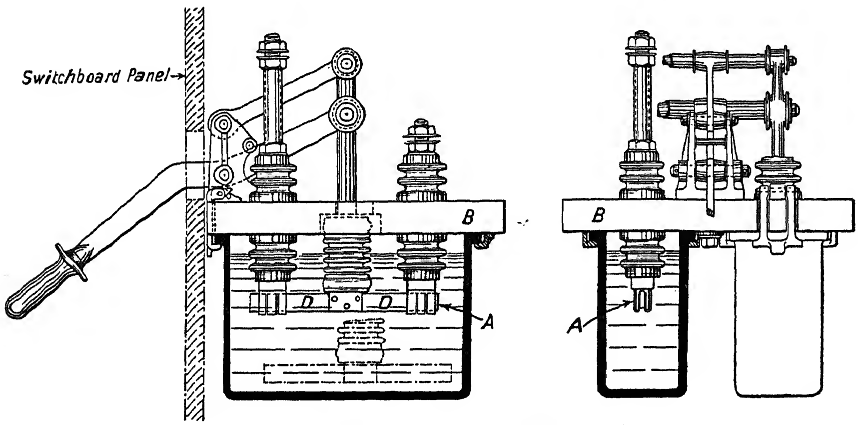



FIG. 67.—Section of Cowan oil break switch.

cient to overcome the friction between the multiple blades and the contacts. The circuit is thus finally broken simultaneously at a number of points under oil. The chief difficulty to be contended with in a switch of this type is that of making it perfectly oil-tight.

An efficient type of oil circuit-breaker that is now becoming very popular in this country, on the Continent, and in the States is illustrated in fig. 67. The ends of the circuit to be completed are connected to inverted contacts A supported from insulators fixed on the under side of the slate slab B. These contacts are short circuited by a connecting piece carried on an insulator at the end of a vertical rod which can be moved up and down by the controlling handle. A vessel containing oil is fixed in such a position as to thoroughly cover the contacts with oil. This vessel is of sufficient depth to allow the connecting piece to be lowered to open the circuit. To examine or clean the contacts it is merely necessary to remove the oil vessel, and this can obviously be done without in any way

disturbing any of the connections or the working parts of the switch. As there are no holes in the oil vessel, trouble from leakage is entirely

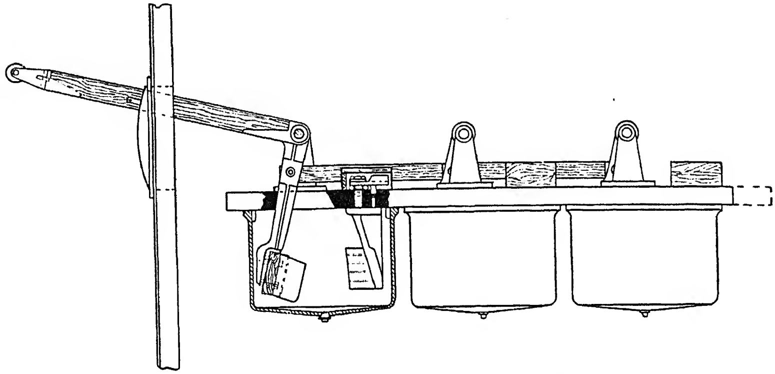


FIG. 68.—Section of Stanley oil break switch.

avoided. In Messrs Cowans' particular adaptation of this principle, illustrated in fig. 67, a truly vertical movement of the rod carrying the

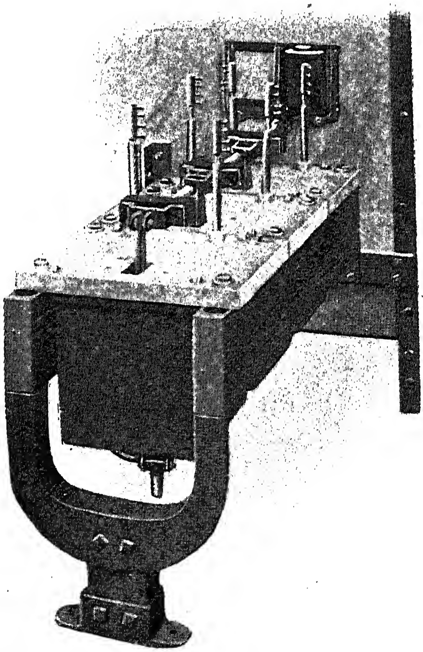


FIG. 69.—Stanley oil break switch in position behind panel.

connecting piece is ensured by the parallel link motion shown. In other constructions this rod is carried in suitable guides.

The use of oil for preventing the formation of an arc is almost universal for the heavy current high-tension circuit-breakers used in the States. The General Electric Co.'s oil circuit-breaker (see figs. 146–148) and the Stanley oil circuit-breaker (figs. 68, 69) are typical examples. In the Stanley oil circuit-breaker the contacts are immersed in oil pots bolted to marble slabs, usually fixed behind the switchboard and operated from the front of the board. The illustration shows a three-phase switch operated by one controlling handle.

**Multiple Break Circuit-breakers.**—An interesting form of this type of circuit-breaker is the British Schuckert Co.'s high-tension roller switch illustrated in fig. 70. When the circuit-breaker is closed the current is carried by the bridge-piece connecting the two main contacts. This

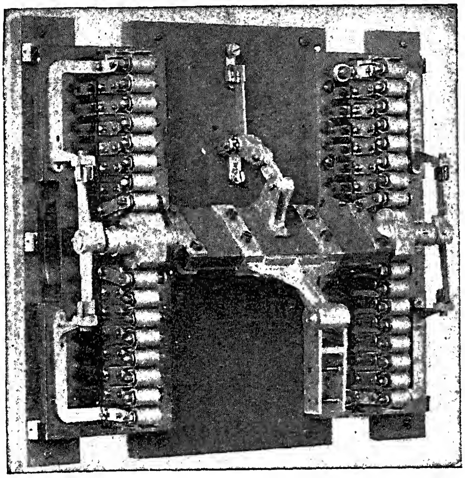


FIG. 70.—British Schuckert H.T. roller switch.

connection is shunted by a number of rollers carried at the extreme ends of small arms insulated from each other. A spring attached to each arm tends to separate each roller from its neighbour, but, when the main contacts are closed, a cam on the main shaft presses all the rollers into contact. When the main contacts are opened the current is momentarily carried by the rollers in contact, but a further rotation of the main shaft allows the rollers to spring apart, and a number of small arcs are established between adjacent rollers. It is claimed that the arc is so thoroughly divided up that the circuit is not maintained, as it would be if the contact was broken at one point only. As a further precaution, the rollers are made of non-arcing metal.

Another form of multiple break circuit-breaker is illustrated in fig. 71. This circuit-breaker was designed by Mr H. F. Parshall, and is in use for

controlling the high-tension circuits in connection with the Shepherd's Bush power station of the Central London Railway. It will be seen that the terminals of the circuit to be completed are connected to contacts on opposite sides of the switchboard panel, and these contacts are connected by a pair of movable arms geared together to be opened simultaneously by the one movement of the operating handle.

**Shutter Circuit-breakers.** — Many designers have devised circuit-breakers in which the arc is interrupted by interposing across its path a shutter of refractory material actuated by the operating handle. The contacts to be connected are usually fixed on insulators behind a marble panel, and the circuit is completed through a ∏ shaped connector, the ends of which fit into the contacts through the holes in the panel. When the circuit-breaker is opened, a shutter drops across the holes in the panel, thus effectually cutting off the arc.

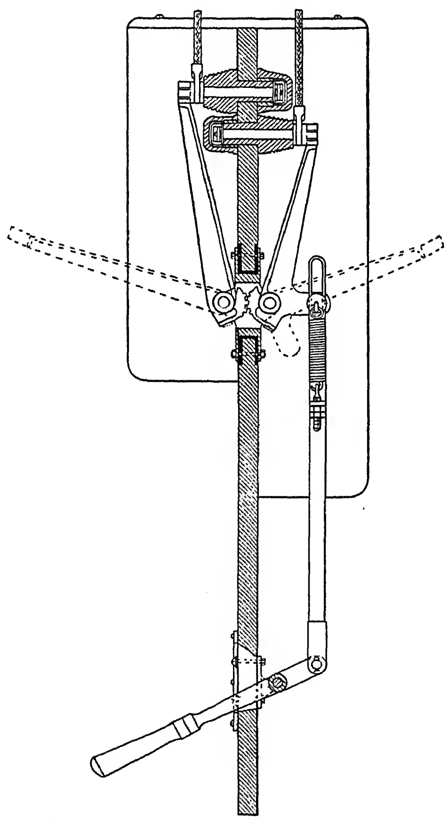


FIG. 71.—Parshall double break switch.

The Peard fuse, illustrated in fig. 72, is an example of a shutter circuit-breaker. It consists of a central block *a* of non-conducting material, separating from each other the terminals *i p* to which the fuse *d* is fastened, this central block having in its centre a movable screen *b*, which is pressed by a spring against the fuse. The fuse is weakened where it crosses the movable screen, to ensure fusion taking place at that point only, and to allow the screen to instantly divide the fuse in two and thus prevent the continuance of an arc. This fuse can be relied upon to break heavy currents at pressures up to 500 volts.

The well-known Mordey dust fuse might also be classed as a shutter circuit-breaker. In this fuse the wire is enclosed in a glass tube, a clear space being left in the middle of the latter. The ends of the tube are filled with an incombustible dust held in place by asbestos washers and the metal

caps at the extreme ends of the tube, to which the fuse wire is electrically connected. When the fuse melts an arc is started across the interrupted circuit, but it is prevented from being maintained between the brass terminal caps by the asbestos washers and incombustible dust referred to, which effectually stifles it. These fuses are quite reliable for currents of from 1 to 5 amperes at a pressure of 2000 volts, and have been, and are still, very extensively used for such small currents.

**Shunted Circuit-breakers.**—The Mordey dust fuse referred to above is sometimes used for shunting heavier fuses. A small resistance is inserted in series with the dust fuse to induce the current to select the path through the main fuse under normal conditions. This main fuse may be merely a wire carried in the open air between two terminals a few inches apart. In the event of an abnormal rise of current the main fuse is blown, the current is then momentarily carried by the shunt fuse, and the circuit finally broken in this. By this means the formation of a destructive arc is avoided.

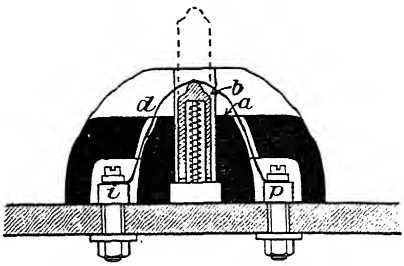


FIG. 72.—Peard fuse.

A light fuse is often used to shunt a low-tension switch, and to break the arc that would be formed in the event of this being opened when carrying a heavy current. By this means the necessity of providing special circuit-breakers, capable of carrying and breaking large currents, is avoided. An instance of the use of fuses for this purpose is referred to in the description of the Edinburgh switchboard, Chapter IX.

# CHAPTER IV.

## AUTOMATICALLY OPERATED CIRCUIT-BREAKERS.

Relative advantages of magnetic cutouts and fuses; lack of time element in the former, and uncertainty in the latter—Examples of excess current cutouts: 'Elwell-Parker,' 'Ward-Leonard,' 'I.T.E.,' 'Schuckert,' 'Cowan,' etc.—Examples of time element excess current cutouts: Clockwork, 'Gibboney,' 'Rucker,' 'Hobart,' 'Charlton,' etc.—Zero or minimum cutouts—'Raworth' zero cutout—Characteristic curves of zero cutouts and various reverse current cutouts—Manchester type of reverse current release.

CIRCUIT-BREAKERS are for many purposes adapted to be operated automatically in the event of abnormal conditions arising. Such automatic circuit-breakers, often called cutouts, may be controlled electro-magnetically or thermostatically. They may be divided into three distinct classes—

(*a*) **Excess current cutouts.**
(*b*) **Zero or minimum current cutouts.**
(*c*) **Reverse current cutouts.**

**Excess Current Cutouts** are adjusted to operate when the current passing through them exceeds a predetermined limit. Such cutouts are largely used in the States instead of fuses, but in this country their use has up to the present chiefly been confined to tramway, railway, and motor work. Both fuses and magnetic cutouts have their advantages and disadvantages. A fuse is usually much simpler and less costly than a cutout, and there is a certain time element about a fuse which cannot be so satisfactorily obtained in magnetic cutouts. That is to say, a fuse rated to carry, say, 50 amperes will possibly blow if a steady current of 75 amperes is maintained for several seconds, and will remain unaffected by a momentary current of double this amount. This feature is a very important one, and various attempts have been made to construct magnetic circuit-breakers to operate in this manner. The rating of fuses is usually not so definite as that of magnetic cutouts. The fuse wire is apt to become deteriorated by the continual use at the high temperature it is, of necessity, raised to when working under normal

conditions, and frequent trouble is caused by fuses blowing when only carrying a normal current. A further trouble is liable to arise through the screws under which the fuse is clamped working loose, thus causing a bad contact, resulting in excessive heating, and the consequent melting of the fuse. This difficulty is particularly apparent in connection with alternating currents. A magnetic circuit-breaker can usually be re-set in a much shorter time than a fuse, and this is a very great advantage for

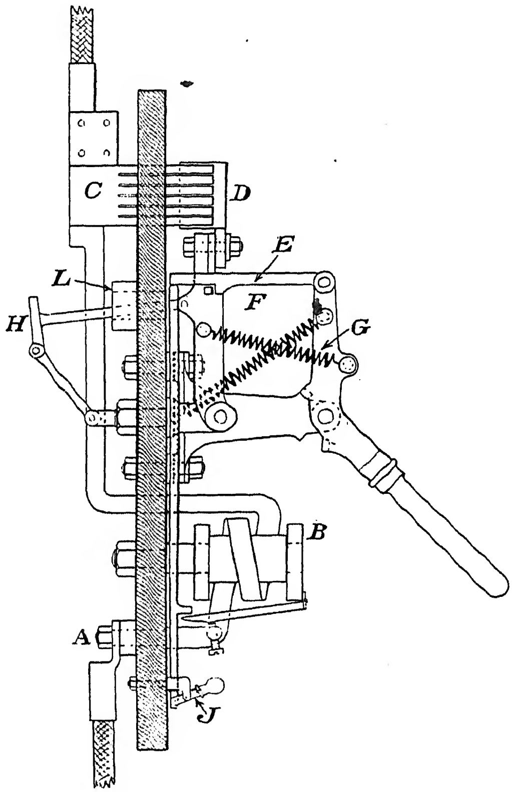



FIG. 73.—Elwell-Parker cutout.

use in connection with traction work, as momentary short circuits, or other causes of abnormal rise of current, are of very frequent occurrence.

One of the earliest types of magnetic circuit-breakers, still largely used, is the Elwell-Parker circuit-breaker, illustrated in fig. 73. One end of the circuit to be controlled is connected to the terminal A. From this it passes round an electro-magnet B and up the back of the panel to a contact C. When the cutout is closed the circuit is completed through a connecting piece D to another contact behind C, to which the other main terminal is connected. An excessive current through the magnet B attracts the

armature of this magnet and trips the catch E. This allows the contact arm F to be opened with great rapidity by the spring G. The extent to

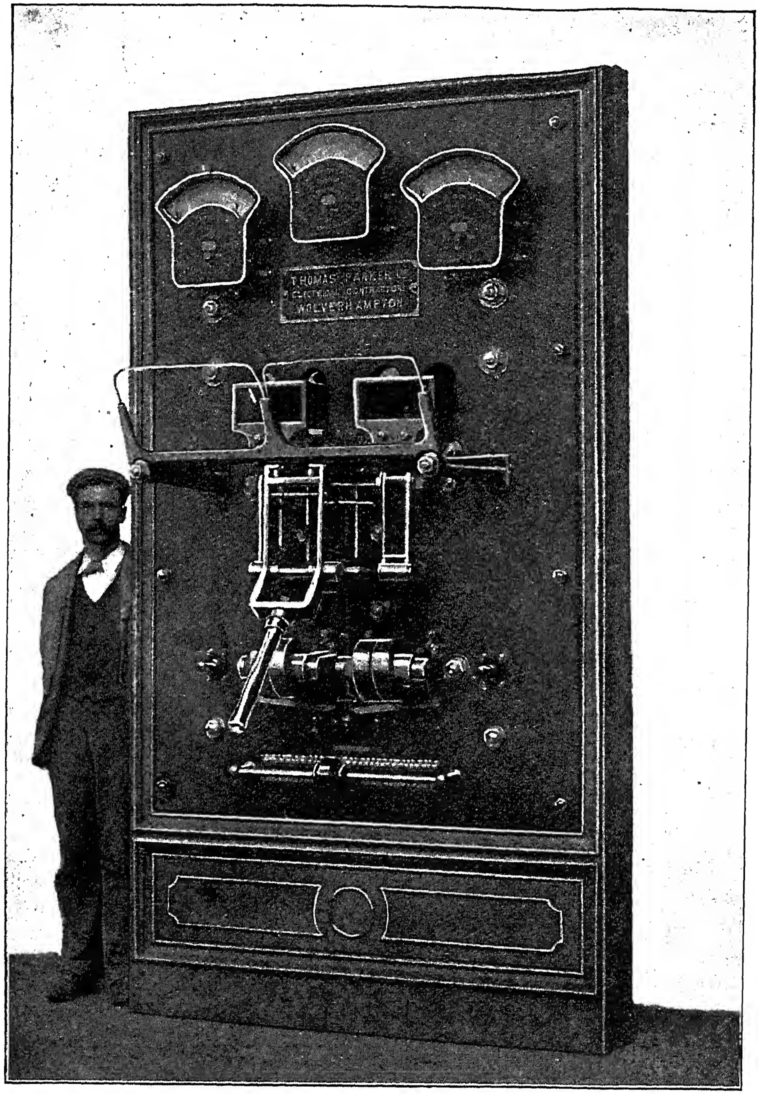


Fig. 74.—Photo of large Elwell-Parker cutout.

which this arm is permitted to fly open is limited by the stop H coming in contact with the rubber ring buffer L. To close the cutout the controlling handle is pulled down, and as the contact arm is prevented by

the stop H from following, the spring G is again extended until the catch E drops into position behind its stop. The operating handle is then lifted, thus closing the cutout. The cutout may be manually released by depressing the small lever J. Fig. 74 is a reproduction of a photograph of a large circuit-breaker designed on these lines to deal with 2500 amperes at 500 volts for the Liverpool Corporation by Messrs Thomas Parker and Co.

One of the most popular methods of releasing the trip of an excess current cutout is that of floating a core in a solenoid. As the magnetic pull upon a core partly immerged in a solenoid is definite for a given current and a given length of core in the solenoid, the current at which the cutout will be operated may be predetermined by adjusting the length of the core within the solenoid. The core under normal conditions rests upon an adjustable stop beneath the solenoid. When the current is reached at which it is desired to release the cutout, the core is floated off its stop and sucked into the solenoid. Immediately it begins to move the pull upon it is increased, and it consequently rises with increased rapidity, gathering momentum as it moves, until it strikes the catch with a smart blow, thereby releasing the cutout.

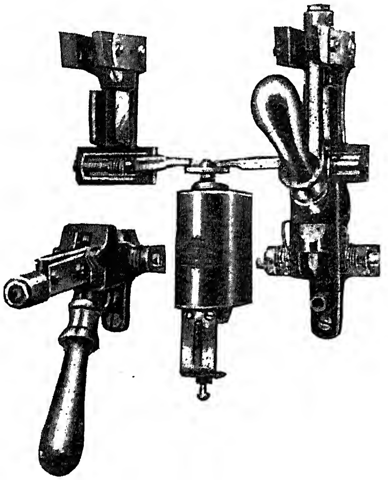


FIG. 75.—Ward-Leonard cutout.

A well-known cutout operated by a plunger release, very largely used in the States, is the Ward-Leonard circuit-breaker, illustrated in fig. 75. In this make of cutout the releasing solenoid is usually fixed by the side of the circuit-breaker. This solenoid is iron-clad, thereby ensuring a very powerful release. It is claimed that the magnetic suction alone, without any hammer blow of the plunger, is sufficient to release the catch. A special feature in connection with this cutout is the use of two circuit-breakers connected directly in series or on opposite poles of the circuit, as may be desired. These circuit-breakers are so constructed that each side of the circuit in the double pole type is separately closed. The instant the current flows, the side of the switch not held by the operator will automatically fly open and break circuit, if an overload or short circuit exists at the time. If an overload occurs later, after the switch has been closed, then both the poles will open simultaneously. In both cases the circuit is instantly broken, and all arcing occurs on the carbon contacts

provided. These carbon contacts are readily replaced by loosening a couple of screws.

Another excess current cutout is the 'I.T.E.,' illustrated in fig. 76. The core is in this case divided, the upper half of it, D, being permanently fixed in the upper half of the solenoid, whereas the lower half, C, rests upon

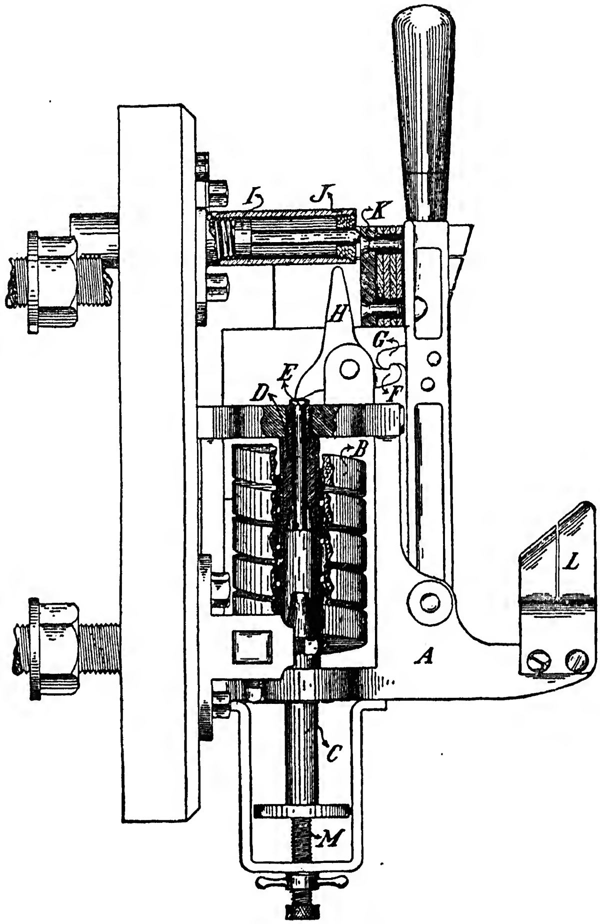



FIG. 76.—'I.T.E.' cutout.

an adjustable stop M below the solenoid. In the event of an excessive current through the winding B the core is sucked up, due to the attraction of the solenoid and the upper half of the core fixed in the solenoid. When the cone portion of the lower half of the core is just entering the hollow cone in the upper core the attraction is very powerful. At this point the floating core hits a pin E, which lifts the catch F and releases the arm carrying the switch contacts K. The contact arm is opened by the spring act-

ing on the plunger I, but this movement is further greatly assisted by the projection H on the catch: thus the lifting core, in addition to releasing the catch, actually hits the contact arm with a smart blow, thereby ensuring its being instantly opened. The contact L merely acts as a buffer to absorb the blow due to the rapid opening of the switch arm.

The British Schuckert Co.'s excess current cutout is also released by

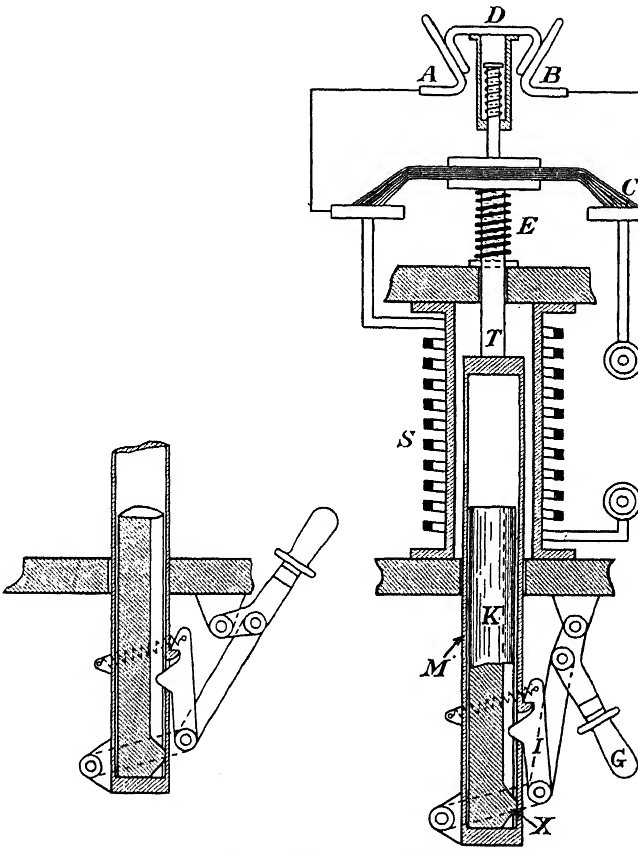



FIG. 77.—British Schuckert cutout.

the attractive action of a solenoid on a floating core. The construction of this cutout is shown diagrammatically in fig. 77. The plunger K is carried inside a non-magnetic metallic tube M. An extension T from the upper portion of this tube carries the main contact C, and indirectly the auxiliary contact D. A powerful spring E tends to lift the main contact piece and open the circuit, but this movement is prevented by a catch I engaging in a projection on the tube M. In the event of an excess current, the core K is sucked up with considerable force, and a projection

X on the lower end of this core impinges against another projection on the catch I, thereby releasing the hold of the catch on the tube M. The spring E is thus permitted to lift the connecting piece from the main contacts, and the circuit is momentarily carried through the auxiliary contacts A, B, and D. The circuit is finally broken at this point, and the arc formed is blown out between the poles of a powerful magnet excited by the main solenoid S. To close the cutout the operating handle G is lifted to the position shown on the left-hand figure, thereby allowing the catch to again engage in the projection on the tube M. The handle is then pulled down, thus closing the main contacts. Should the short circuit still be on, the rush of current through the solenoid again lifts the core and releases the catch. It will be obvious that the releasing action is not interfered with by the operating handle being held in the closed position.

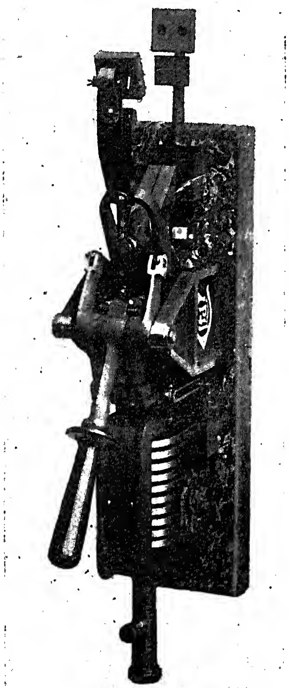


Fig. 78.—Cowan J.M. cutout.

A simple and efficient magnetically operated circuit-breaker, manufactured by Messrs Cowans, Ltd., is illustrated in figs. 78 and 79. The circuit to be controlled is conducted from the main terminal A (fig. 79) through the operating solenoid B and main jamb brush contact C C to the second main terminal D. The main jamb contacts are shunted by auxiliary copper contacts $C^1$ $C^1$ and carbon contacts $C^2$ $C^2$. The circuit is broken first across the main contacts, but as the current is carried momentarily by the low-resistance shunt contacts $C^1$ $C^1$, all arcing at the main contacts is entirely prevented.

The necessity of this intermediate break between the main and carbon contacts has not always been properly appreciated. Experience has shown that automatic circuit-breakers of a normal carrying capacity of a few hundred amperes are at times required to break currents of several thousand amperes, with the result that, if the main contacts are shunted by comparatively high resistance carbon contacts only, the E.M.F. across the main break due to the $C^2R$ drop of the carbon shunt is often sufficiently high to establish such a destructive arc across the main contacts as to burn up the circuit-breaker. The contacts $C^1$ $C^1$ act, therefore, as sparking pieces, and as these can be easily renewed,

little damage is done by opening an abnormally heavy current. It is of course imperative that these contacts be kept in moderately good condition, as, should they be used after they have been severely burned, the resistance

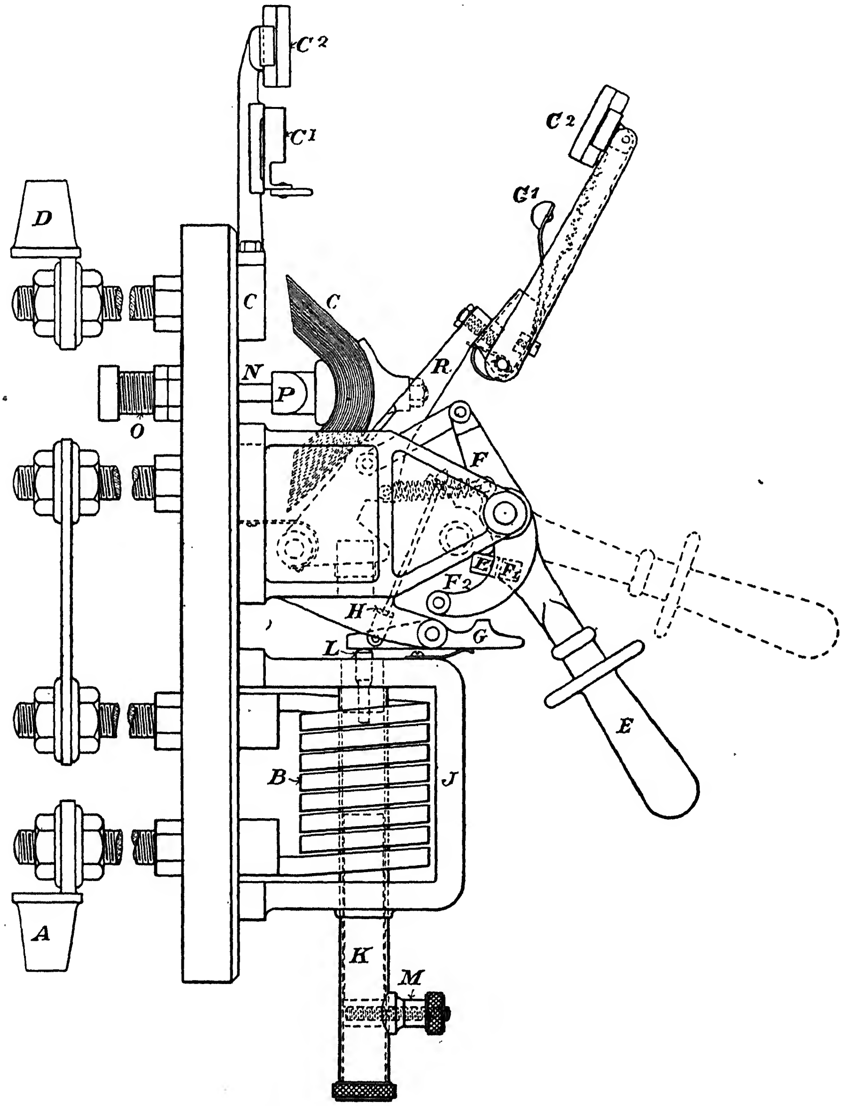



FIG. 79.—Details of the Cowan J.M. cutout.

of this path may be almost as high as that of the carbon break, and the object of the intermediate break will therefore be defeated.

An important feature of this cutout is the method adopted of carrying

the main jamb brush C. It is of course important that an excess current cutout should open instantly on a heavy short circuit. To ensure this the moving arm should be kept as light as possible. If the heavy jamb brush is carried by the moving arm, the inertia to be overcome is so appreciable that the movement of the arm is considerably retarded by it. In the Cowan cutout the jamb brush is carried on a spindle N, working in a bush O fixed in the base of the cutout. A powerful compression spring in this bush tends to open the cutout. It is closed against the action of this spring by the moving arm R pressing against the projections P on each side of the jamb brush support.

To close the circuit-breaker the operating handle E is lifted to the position shown dotted. The projection $E^1$ on the handle engages with the projection $F^1$ on the toggle-jointed lever F, and thereby straightens the toggle joint and forces the jamb brush C against its solid contact blocks with considerable pressure. It is held in this position after the handle is released by the roller $F^2$ engaging in the catch G. To release the circuit-breaker by hand the loose handle is depressed until the catch G is lifted by the connecting link H. In a slightly modified construction of this cutout provision is made to allow the circuit-breaker to open—if closed on a short circuit—whilst the handle is retained in the closed position.

The operating solenoid is wound with heavy-section rectangular copper strip rigidly supported from its terminals. The air spacing between the respective turns is the only insulation required. The magnetic circuit is completed through the iron yoke J. A floating core rests on an adjustable stop M in a brass tube K. An abnormal current draws the core into the solenoid, and it strikes the pin L with considerable force and releases the catch.

**Time Element Devices.**—Reference was made in the early part of this chapter to the lack of time element about an excess current cutout as compared to a fuse. This has proved a great drawback in the use of magnetic cutouts, for when, as often happens, two or three cutouts of different carrying capacities are arranged in series, a short circuit that should only operate one cutout will operate all the cutouts in the series. For instance, a cutout may be fixed at a main generating station which should only operate in the event of a short circuit on the feeders between the generating station and the distributing station. A second cutout may be placed on the converters; this should only operate in the event of a short circuit in the converter itself. A third cutout may be placed between the secondary windings of the converter and the distributing 'bus bars, and a fourth between the 'bus bars and each of the distributors supplied from the secondary 'bus bars. Now, in the event of a short circuit occurring on one of these distributors, it is obviously desirable that only that particular distributor should be cut off. This can usually be accomplished

by the use of fuses, the fuses nearest the generating station being most heavily rated, and the rating being gradually reduced towards the distributors. A current that will blow a given fuse in, say, one second will, if maintained, blow a larger fuse in two seconds, and a still larger fuse if maintained for three seconds. It will be evident, therefore, that if a number of fuses of different sizes are connected in series, the smallest fuse will generally blow first and protect the larger fuses. This protection of larger cutouts by smaller ones is also attempted in the use of magnetic cutouts, and to a certain extent it is successful. It often happens, however, that a short circuit on a distributor allows sufficient current to pass before it is interrupted to operate the largest cutout, and as there is no time limit in connection with these cutouts, the larger ones open simultaneously with the smaller ones, thus interrupting the supply to a very much larger portion of the system than is necessary.

To overcome this difficulty various attempts have been made to construct time limit cutouts. One device of this description is shown in fig. 80. A clockwork mechanism tends to rotate a disc A in the direction indicated by the arrow, but this rotation is normally prevented by a catch B engaging in the fan H. A solenoid C carries the main current of the circuit to be controlled, the operating solenoid of the cutout, J, usually deriving its energy from a local source K. Connected in series with this local circuit are two brushes D and $D^1$. The brush D makes permanent contact with a disc E carried by the rotating clockwork mechanism. Attached to this disc is an insulating drum F, which carries a contact stud G electrically connected to the disc E. The brush $D^1$ is normally not in contact with the drum F. In the event of an abnormal current, the core of the solenoid C is lifted, and the clockwork mechanism is released and allowed to rotate. At the same time the brush $D^1$ is caused to make rubbing contact with the revolving drum F. The local circuit is not, however, completed until this drum has made almost a complete revolution, thus bringing the contact G opposite the brush $D^1$. The rate at which the drum rotates may be predetermined by adjusting the angle of the aluminium blades H. Should the short circuit not be maintained until the contact stud G comes in contact with the brush $D^1$, the core in the solenoid C will be released, and this in turn releases $D^1$ from rubbing contact with the revolving drum F. The contact G will thus pass $D^1$ without completing the circuit, and at the end of the complete revolution the catch B will drop into the notch in the disc A, and so stop the mechanism and leave it in readiness for another short circuit. The idea is that a number of cutouts controlled by these time limit devices shall be connected in series, the cutouts on the final branches being left to operate instantaneously, and the time limit devices in series being adjusted to operate after an interval of one, two, three, or four seconds, respectively; those

nearest the generating station being, of course, adjusted to take the longest time.

A difficulty has arisen in connection with the type of time limit device referred to above. Experience has shown that, on a system where there is a large amount of synchronous apparatus in operation, if a short circuit

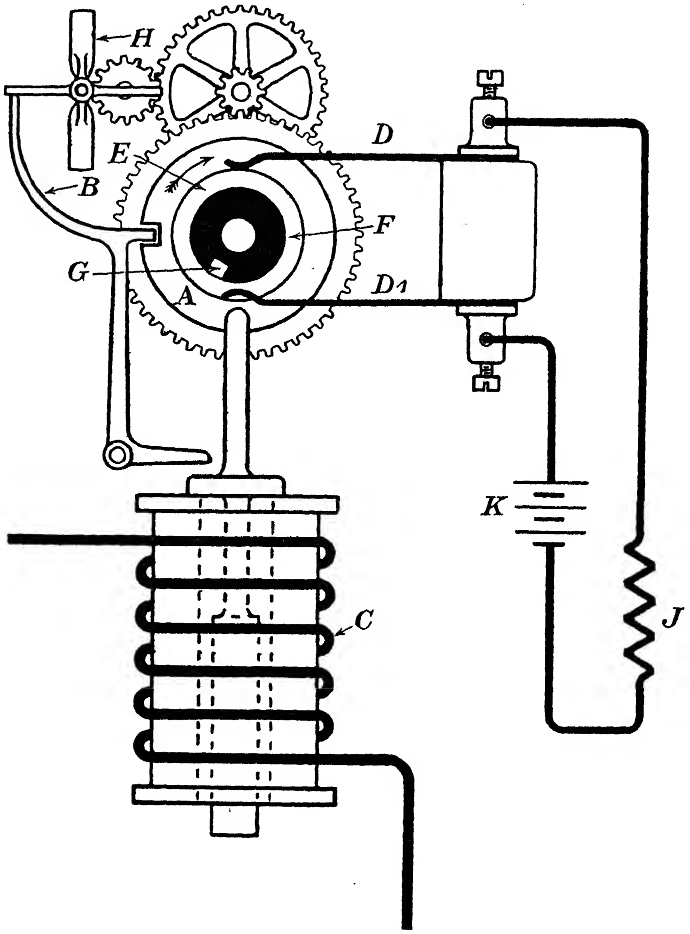



FIG. 80.—Clockwork time element device for cutouts.

occurs it must be disconnected at once, or else the prolonged drop in voltage will cause all the synchronous apparatus to drop out of step; whereas, if the short circuit can be disconnected instantly, the inertia of the rotating parts of the synchronous apparatus will keep them in step for this short period. For this reason, the above type of time limit relay is objectionable, since it causes a delay in cutting off the faulty section.

In connection with the new generating plants of the Niagara Falls Power Company, a new form of time limit device, designed by Mr W. K. Gibboney, of the Power Company, is now being used. This device consists of a dash-pot attachment to the tripping plunger of the circuit-breaker. This retards the movement of the plunger, and consequently the opening of the breaker, for ordinary temporary overloads; but if a real short circuit

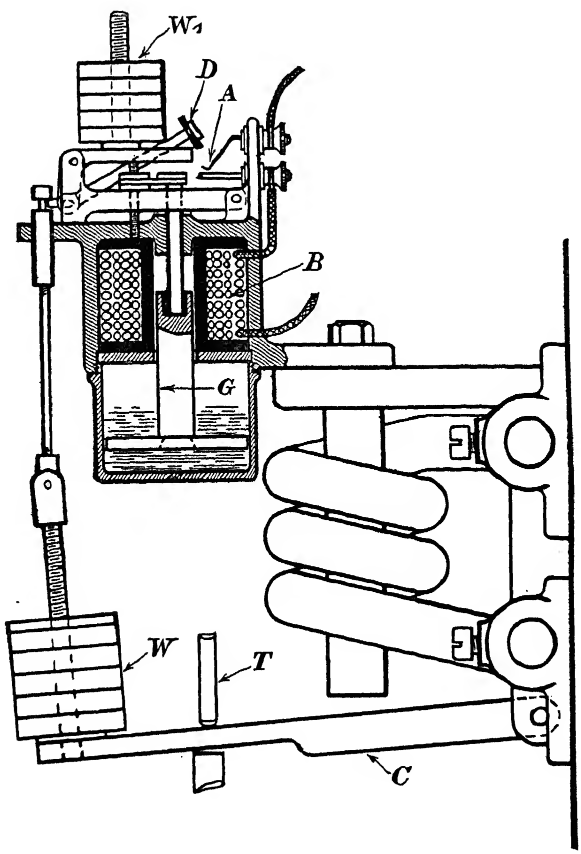



FIG. 81.—Rucker's time element device.

occurs, the pull on the plunger is so strong that the dash-pot has no effect, and the circuit-breaker opens instantly.

A novel time limit device, patented by Mr B. P. Rucker, is illustrated in fig. 81. The chief feature of this device is the addition of an auxiliary weight to the armature or core of the ordinary tripping magnet, an additional magnet being used for removing the auxiliary weight in the event of the overload or short circuit being maintained for a predetermined time. The cutout is calibrated by adding weights W to the armature of the

tripping magnet until the magnet is only just able to overcome the weight when excited with the current at which it is desired the cutout shall operate at the end of, say, five seconds, or any other predetermined time limit. Sufficient auxiliary weight $W^1$ is then added to prevent the armature lifting until it is excited by the current at which it is desired the cutout shall operate instantaneously. If the magnet is excited by a current greater than that necessary to lift the weight W alone, the armature C will be slightly lifted, thereby allowing the lever D to drop and close the contact A, thus completing a local circuit through the winding B. This slight movement of the armature now throws the weight $W^1$ on to the weight W, and the magnetic pull must be sufficient to overcome both these weights if the cutout is to be instantly released. Although the current in the main solenoid may be insufficient to do this, the auxiliary winding will lift its plunger G, and if the overload is maintained for the predetermined time this plunger will lift the weight $W^1$, thereby leaving the main solenoid nothing to do but to lift the weight W and the rod of the tripping device T. The auxiliary winding is prevented from lifting its core, immediately the local circuit is closed, by an oil dash-pot. Should the overload not be maintained for the full time limit, the main armature will again be allowed to drop, and this in falling will break the local circuit through the auxiliary winding at the contact A, and the auxiliary plunger will again fall to its normal position.

Mr H. M. Hobart has recently devised an interesting time limit circuit-breaker. He arranges the tripping coil of the circuit-breaker in a divided circuit, the branches of which are of different time constants, and are connected to the circuit upon which the cutout operates. In the branch containing the tripping coil is placed an inductive device which serves to retard the growth of current in this branch when the current in the main circuit varies. The other branch of the divided circuit is formed so as to offer no impediment either to the growth or decay of rapidly varying currents. The result of this plan is that, when the current in the main circuit suddenly increases, the portion of the same passing through the tripping coil increases but slowly, while that in the branch circuit shunting the tripping coil rises instantly to its full value. Unless the main current is maintained for that predetermined interval for which the parts are proportioned, the circuit-breaker will fail to act, the main current returning to a value or values below that for which the circuit-breaker is set. In case, however, the overload current lasts for a length of time sufficient to allow the current in the tripping coil branch to rise to a steady value, the circuit-breaker will then operate.

Fig. 82 illustrates diagrammatically a thermo-electric cutout invented by Messrs Charlton and Barton. A powerful spring A tends to open the circuit between contacts B and C, but is prevented from doing so by a

catch D. This catch is in turn held by an arm E, bolted to a tripping rod F. The spring G tends to lift the tripping rod and arm, but this movement is prevented by a tail-piece engaging in a projection on the lower end of the double-fulcrum lever H. This lever is hung from a pair of insulated brackets securely fixed to the conducting strips I, J. These strips are rigidly fixed at each end; consequently any expansion of the strips is bound to cause them to bulge outwards, and the effect of this will be to move the lever H in the direction indicated by the arrow, thereby releasing the trip rod and allowing the cutout to open. The rate at which the device operates

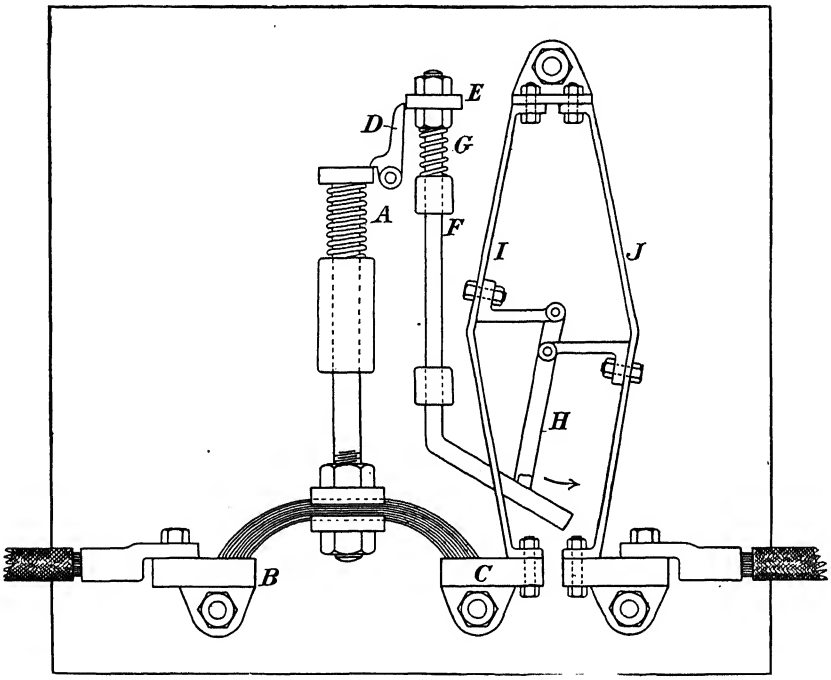



FIG. 82.—Barton's time element thermal cutout.

is obviously governed by the amount of excess current. A very heavy current will release the catch instantly, whereas a current slightly in excess of the normal will take several seconds to do so. It has, in fact, a time constant very similar to that of a fuse. The rating of the cutout may be adjusted by varying the height of the arm E. The device is, in practice, constructed to be reset by one movement of an operating handle.

**Zero or Minimum Cutouts.**—A number of switchboard makers have designed cutouts to operate when the current falls below a predetermined amount. These cutouts are chiefly used to disconnect a generator working in parallel with other generators or batteries, in the event of the said

generator failing to supply current to the system. The idea is that, should a generator fail, its current will fall to zero before it commences to receive current from the other generators.

An interesting zero cutout, designed by Mr J. S. Raworth, is illustrated in fig. 83. This cutout, in addition to disconnecting a dynamo in the event of its ceasing to generate current, was intended to also switch an incoming dynamo into circuit when the pressure across its terminals equalled the pressure of the 'bus bars. It will be seen that the connecting tongue for completing the circuit between the two contacts is carried on a vertical rod A, which carries an iron armature B. This armature moves between two magnets C and D, of which the lower one, C, is magnetised by a shunt from the mains, and demagnetised by a shunt from the generator terminals. The upper magnet, D, is magnetised by the main current passing from the dynamo to the station 'bus bars. When the dynamo is at rest the lower magnet holds the armature down and locks the switch out of action, and it is held in this position until the pressure across the dynamo is approximately equal to or slightly greater than the pressure across the 'bus bars. When this point is reached the two windings on the magnet C neutralise each other, and allow the weighted lever F to close the switch, thus completing the circuit. The switch is held in a closed position by the magnet D. In the event of the generator controlled by this cutout failing, the magnet D releases the switch, which falls by gravity and opens the circuit. The weighted lever F has, on starting the engine, to be put in gear with the switch by means of a small catch or pawl, which is automatically released when the switch closes.

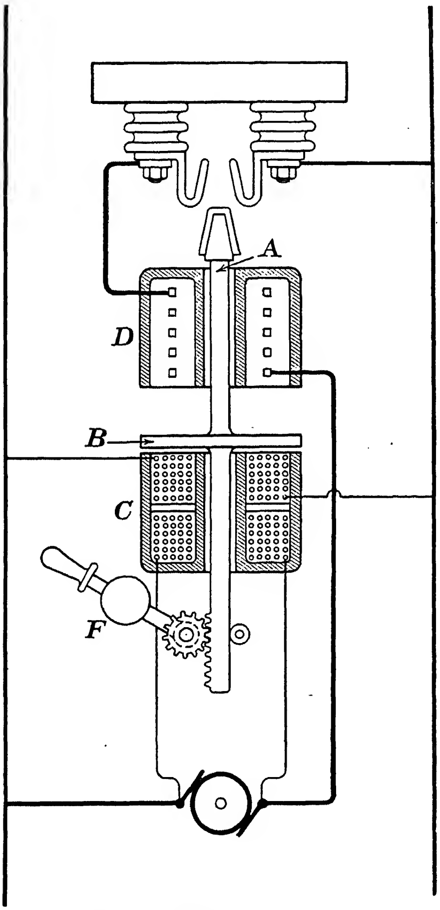



FIG. 83.—Raworth zero cutout.

This cutout was arranged in a switch pillar equipped with an ammeter and voltmeter, placed near the generator which it controlled. It was claimed that this apparatus entirely prevented accidents from (*a*) closing the switch when the dynamo was unexcited or not giving full E.M.F., (*b*) closing the switch when the polarity of the dynamo was reversed, (*c*) current coming back on the dynamo and blowing the fuses. It has been generally felt, however, that it is better not to attempt to carry automatic switching to such an extent as is done in this apparatus.

Zero cutouts have not, in practice, proved reliable, and as a consequence they are now being, to a great extent, replaced by reverse current or return current cutouts—that is to say, by cutouts which will not be

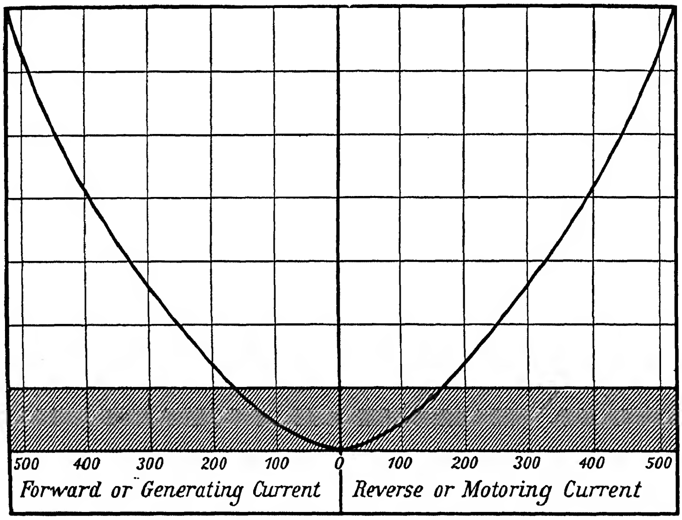



FIG. 84.—Characteristic curve of zero cutout.

operated by the current falling to zero, but require a definite current in the reverse direction to the normal to release them.

It is not, perhaps, generally recognised that the behaviour of a reverse current cutout can be shown by its characteristic curve. The characteristic of an ordinary zero current cutout is shown in fig. 84. Let the ordinates of the curve represent the torque or pull due to any current in a normal or reverse direction, and let the abscissæ plotted to the right and left of the vertical zero line represent the current in the tripping coil, the forward current being plotted to the left of the zero line and the reverse current to the right of this line. Let the shaded area represent the pull within which the cutout will be operated. Now, it will be evident that, so long as the generator controlled by this cutout is supplying to the system a current exceeding 150 amperes, the cutout will maintain the circuit

closed. Should the current fall, even momentarily, below this point, the curve drops into the shaded area and the cutout will be liable to open. It is apparent, therefore, that this shaded area must not be carried too high, or the generator will be liable to be cut out when doing very useful work. If, on the other hand, the shaded area is kept too low, the part of the curve in the shaded area is relatively so small that there is always a risk of the cutout being momentarily held in on a sudden reversal until the current begins to rise in the opposite direction, when it will, of course, entirely fail to release the cutout. The impossibility of fixing the height of the shaded area so as to reliably overcome both of the difficulties referred to has, as previously stated, led to this type of cutout being in many cases abandoned. In some installations, such as at McDonald Road, Edinburgh (see Chapter IX.), no automatic cutouts of any description are used between the generators and the main 'bus bars.[1] Manually operated circuit-breakers are provided instead, and it is left to the switchboard attendant to switch out any machines which may fail. To indicate to the attendant which machine is failing, ammeters are used which only give a reading when carrying a forward current. Should a generator fail, the ammeter in circuit with that generator will stand at zero, although a heavy reverse current may be passing through it. In the majority of direct current stations reverse current cutouts are, however, used, and as these can undoubtedly now be made to operate with certainty in the event of a generator failing, and to remain untripped so long as the generator is doing useful work, it appears that the greatest immunity from failure can be obtained by employing some device of this description.

**Reverse Current Circuit-breakers.**—A number of designers have constructed cutouts to operate only when the direction of the current is actually reversed; that is to say, they are not operated by the current in the series winding of the release falling to zero. This object may be attained by using a compound wound magnetic device for the release. The series winding of this release carries the main current from the generator, and the shunt winding is connected across the 'bus bars or across leads of opposite polarity. This shunt winding is in one construction connected up to magnetically assist the series winding when the generator is supplying current to the 'bus bars, and to oppose the effect of the series winding when the generator receives current from the 'bus bars. Curve AA, fig. 85, represents the pull due to the series winding only. Curve BB gives that due to the shunt winding only, and curve CC gives the resultant pull due to the two windings combined. It will be seen that curve CC does not drop into the shaded area until after the series current has fallen through zero and

[1] The recent complete interruption of the supply from the Westminster Electric Supply Company's system has emphasised the danger of not using reverse current cutouts in generator circuits.

has begun to increase as a motoring current. Cutouts of this type are, therefore, not liable to give so much trouble as the ordinary zero or minimum cutout, though it will be seen that if the motoring current rises very quickly, as it would be liable to do if, for instance, the brushes of the generator controlled were accidentally short circuited, the cutout would probably fail to act before the curve again rose out of the shaded area, in which case it would be prevented from operating at all.

Another serious defect arising in connection with cutouts of this type is that they will be operated by a momentary failure of the series and shunt currents, such as, for instance, might occur with a number of machines excited in parallel, in the event of their excitation momentarily failing.

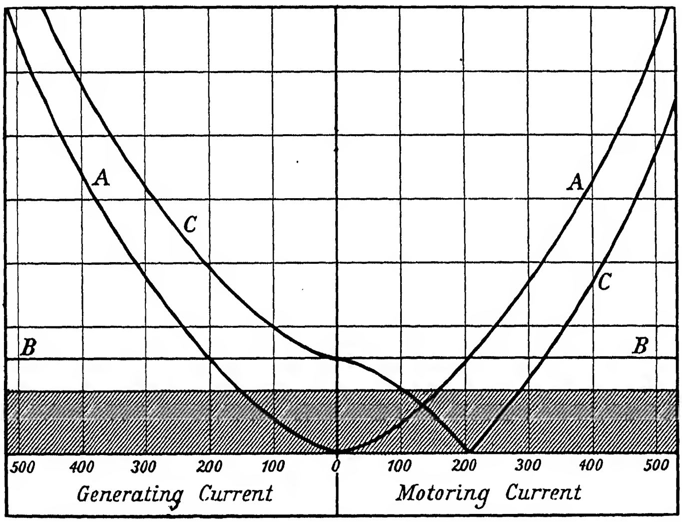



FIG. 85.—Curve of compound wound cutout. Shunt normally helping series.

Cutouts of this type are for the same reason quite useless as protective devices on the distributing end of feeders, as in the event of a momentary interruption to the supply all cutouts would open, and it would be necessary to send attendants round the entire district to replace the cutouts before the supply could be continued.

**Positively Operated Cutouts.**—The characteristics shown in figs. 84 and 85 both refer to cutouts depending for their action upon a negative release; that is to say, they are operated when the magnetic pull is insufficient to overcome the opposing pull due to gravity or a spring. It is preferable, however, that this release should be effected by a positive magnetic pull, somewhat upon the lines of the excess current cutouts referred to in the early part of this chapter. Several reverse current cutouts of this type have been put on the market, a simple compound

wound solenoid release being used. The shunt winding is in this case connected up to oppose the series winding under normal conditions—that is to say, with the current in a forward direction--and to assist the series winding in the event of the direction of this becoming reversed. The characteristic curve of a cutout constructed upon this principle is shown in fig. 86. The drawback to this type of release is that all the generators in a station are very liable to be cut out of action by a short circuit on the mains. The effect of such a short circuit would be to cause a serious drop in the E.M.F. and this would lead to a corresponding drop of the current in the shunt winding; that is to say, the tendency to prevent the heavy generating current from operating the cutouts would be reduced, whereas

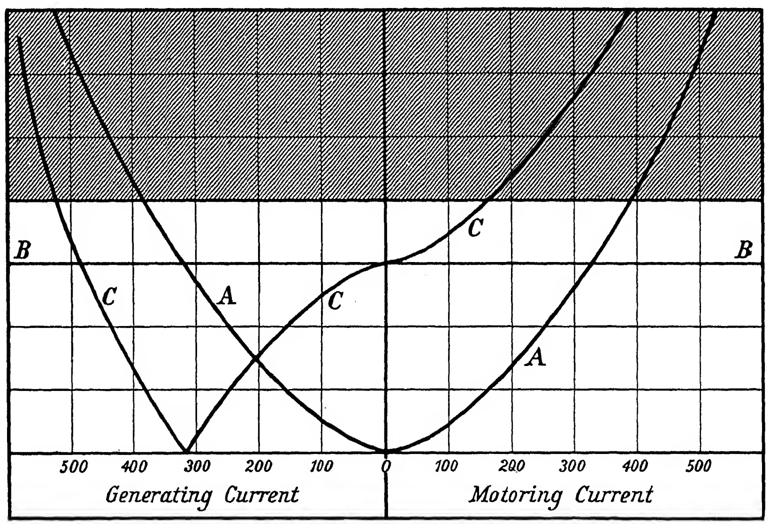



FIG. 86.—Curve of compound wound cutout. Shunt normally opposing series.

the series effect would be considerably strengthened by the heavy current due to the short circuit.

Quite apart from this, it will be seen that, in the curve reproduced, the ratio of the motoring current to the generating current required to operate the cutout is only 1 to 3. That is to say, if the cutout is set to release with a reverse current of 150 amperes, it will also release with a forward current of 450 amperes. This ratio may be increased by raising the height of the curve BB, but if this is carried much higher the shunt winding alone will release the cutout.

The ideal release for reverse current cutouts is one that is positive in its action in both directions; that is to say, the pull tending to prevent the cutout from being released with a generating current should be positive, and the pull tending to operate the cutout on a reversal of current should

also be positive, and in an opposite direction. This double positive action can only be obtained by cutouts having a curve that crosses the horizontal zero line on a reversal of current. Such a curve is shown in fig. 87. It represents the characteristic of the differential shunt winding release illustrated in fig. 95, and is practically the same shape on alternating or con-

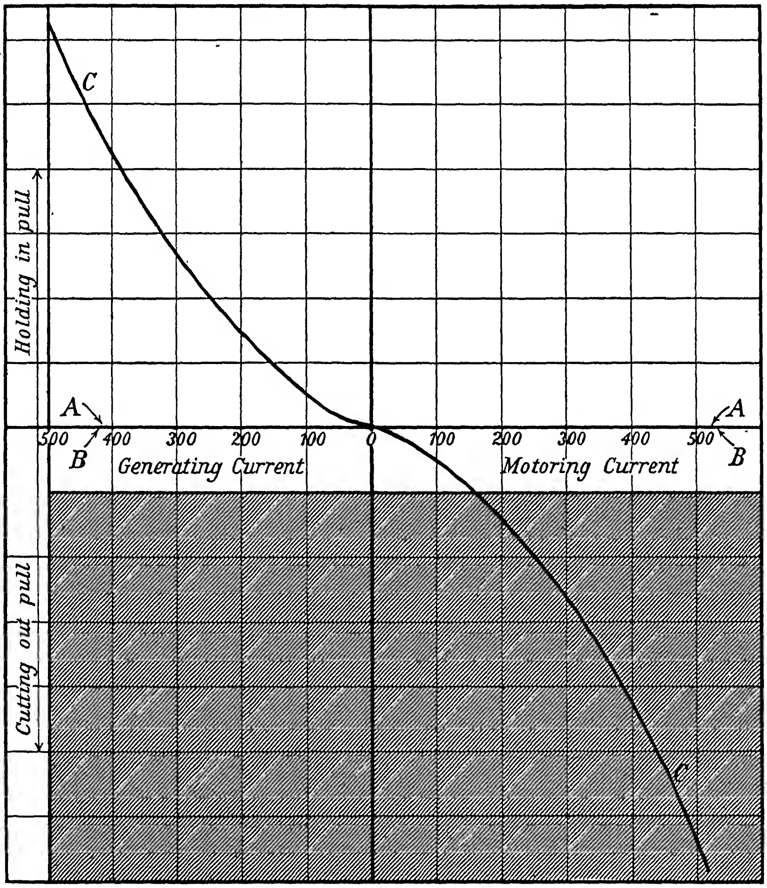



FIG. 87.—Curve of differentially wound shunt cutout.

tinuous current circuits. The author has endeavoured, in designing other types of cutouts, to obtain a characteristic curve approaching this one, but has never succeeded in obtaining quite such a perfect curve with any other type of release for continuous current cutouts. In fig. 87 curves AA and BB are coincident with the zero line—that is to say, the pull due to a current in either the series winding or in the shunt winding alone is nil; but with a given current in the shunt winding the pull due to the current in the

series winding is represented by the curve CC. It will be seen that this pull is in one direction when the series winding is carrying a generating current, and in the opposite direction when carrying a motoring current. Consequently, no amount of forward current will operate the cutout. On the other hand, should it fail to release at the reverse current for which it is set, the cutting-out pull will continue to increase in proportion to the reverse current.

It is often stipulated in specifications for reverse current cutouts that the cutout must release with a reverse current of less than 10 per cent., or even less than 5 per cent. Now, although it is quite possible to construct

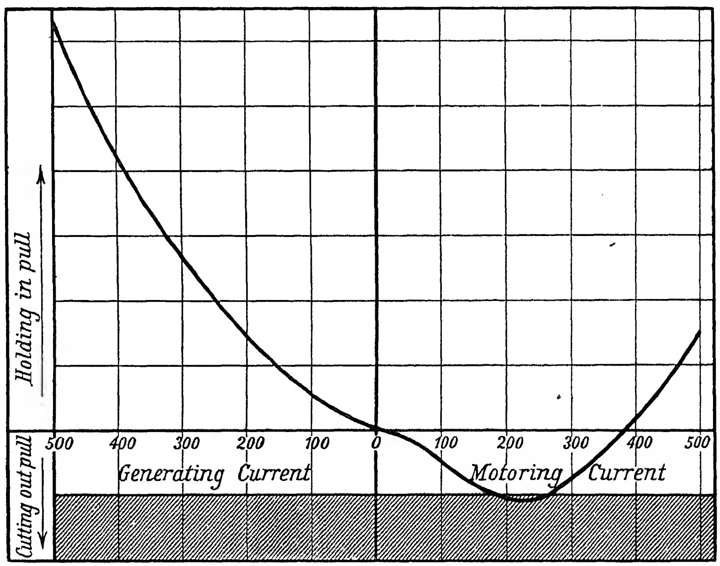



FIG. 88.—Characteristic curve of shunt motor type of release.

cutouts to release at these very low currents, it can only be done at a considerable sacrifice in other directions. It is extremely difficult to construct a simple, direct-acting, and positive torque release that can be relied upon to open a heavy current cutout with a reverse current of less than 10 per cent. of the full load current, and also with a reverse current equal to, or 100 per cent. in excess of, the full load current, and that will under no conditions release with a generating current.

The inherent difficulties of this problem must be apparent to anyone who considers the question. The series of the release coil must carry, without injurious heating, the full load current. It can therefore seldom be worked at a current density exceeding 2000 amperes per square inch, and if the cutout is required to operate at 5 per cent. of the full load current,

it must do so with a current density in the series winding of less than 100 amperes per square inch. Anyone who has experimented with an open solenoid at this low current density will have found that the magnetic forces available are exceedingly small, and quite inadequate for operating the release mechanism of a large magnetic cutout.

These small resultant forces may of course be used for operating a delicate relay, but unnecessary complications are introduced by so doing; added to which, the relay may operate and yet fail to close the local circuit, owing to bad contacts.

It is difficult to understand why such delicate settings are ever called for, unless it is with the idea that if a cutout will operate with a reverse current of, say, 10 per cent., it will be doubly and trebly certain to do so on reverse currents of 20 per cent. or 30 per cent. This supposition is,

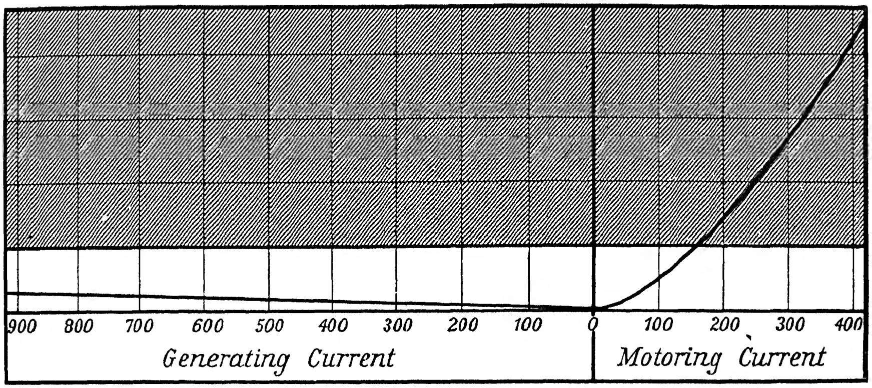



FIG. 89.—Curve of Manchester dynamo type of cutout.[1]

however, quite an error. The author has tested a number of different types of positive torque cutouts[2] that operated perfectly on reverse currents of 5 per cent. and 10 per cent., but that entirely failed to operate on reverse currents of 100 per cent. or 200 per cent. It was found on plotting the characteristic curves of these cutouts that some such results as are shown in fig. 88 were obtained.

The behaviour through the whole range of conditions under which a reverse current cutout is usually tested was perfect; but on carrying the reverse current readings higher, it was found that the direction of the pull was again reversed, and that it became a holding-in pull, when a cutting-out pull was required. This is partly due to the fact that in many types

[1] Since the above curve was plotted it has been found possible to so modify the construction of this release as to make the ratio of the motoring pull to the generating pull greater than 1000 to 1.

[2] Cutouts that have a pull in one direction with generating currents, and in the reverse direction with motoring currents.

of cutout the ampere turns in the series winding are apt to overpower and obliterate the effect of the ampere turns in the shunt winding, and consequently all sense of direction is destroyed.

It must be remembered that it is of far greater importance that cutouts should operate under the very excessive reverse currents that are liable to constantly occur in practice, than that they should merely show a good laboratory performance; and it is probable that, if specifications were drafted to call for cutouts that would never release on a forward current, would operate on a reverse current of 25 per cent., and that *would not fail*

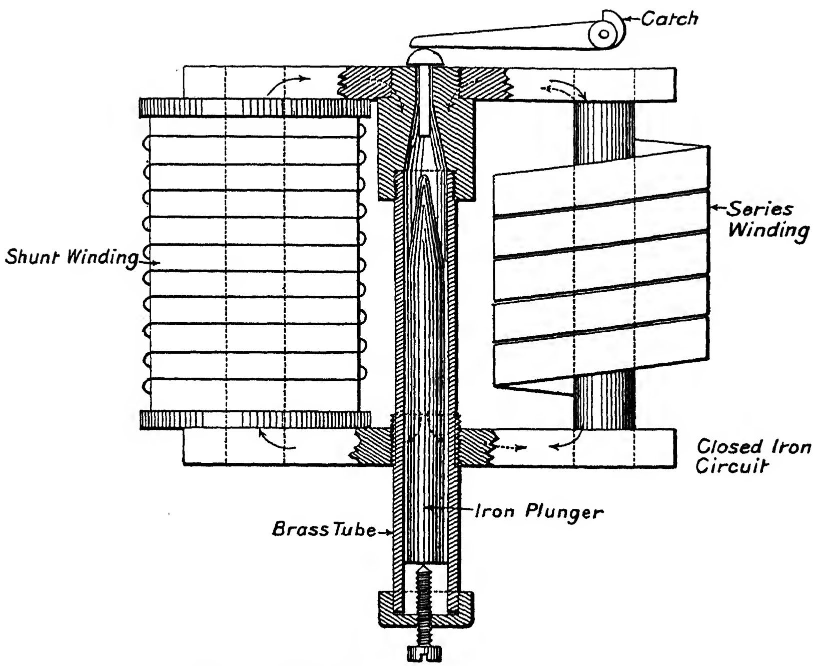



FIG. 90.—Manchester dynamo type of cutout.

*to operate on any reverse current in excess of* 25 *per cent.*, troubles with this class of apparatus would be unheard of.

It may be thought that a release coil constructed to influence an almost closed iron circuit would give better results with a low current density than an open solenoid, and to a certain extent this is true. The majority of nearly closed iron circuit-release devices are, however, particularly liable to possess characteristics similar to fig. 88, and cannot in consequence be relied upon to operate on a heavy reverse current.

The author has recently designed a closed iron circuit release, the characteristic curve of which is reproduced in fig. 89. It will be seen that this device can be relied upon to give a powerful release pull with a 25

per cent. reverse current, and a steadily increasing pull for higher reverse currents. On the other hand, a forward current 200 per cent. or 300 per cent. in excess of the normal full load current will not operate the cutout.

The construction of this device is shown in fig. 90; it resembles the field magnets of a Manchester type dynamo, the series winding being on one limb and the shunt winding on the other. In place of the armature, an iron plunger rests on an adjustable stop. Under normal conditions the series and shunt windings both produce fluxes that tend to flow round the closed iron circuit in the direction shown by the full arrows. There is in consequence no appreciable tendency for the flux to leak across the gaps through the floating plunger. Should the current in the series winding be reversed relatively to that in the shunt, the resultant fluxes will oppose each other, as shown by the dotted arrows, and will in consequence be diverted through the plunger, which will thus be attracted up, striking the releasing catch a sharp blow.

## CHAPTER V.

### ALTERNATING REVERSE CURRENT DEVICES.

The use of fuses between alternating current generators and 'bus bars—The need for automatic cutouts, or some device for indicating which generator is failing—The 'Raworth' discriminating fuse—A simple series and shunt wound solenoid for operating discriminating cutouts—The disadvantages of this arrangement—The use of a double shunt wound solenoid for this purpose—A simple catch for controlling operating weight of cutout—The necessity of adjusting induction of shunt circuit to meet all conditions—A closed iron magnetic release for reverse current cutouts—The use of a cutout release as a relay to close a local circuit through a lamp to indicate failing generator—A simple indicating transformer for this purpose—The uselessness of attempting to protect duplicate mains by fuses—The attempt to use return current cutouts, and the use of a discriminating choking coil for this purpose—A method of automatically operating the switches at the distributing end of duplicate mains by a static relay—Other methods of automatically controlling these switches—The application of discriminating choking coils to polyphase duplicate transmission lines—Protection of multiple feeders.

The various reverse current cutouts referred to in the previous chapter have all been designed to deal with direct current circuits. It is, however, equally important to use some protective device of a similar description for the control of alternating current systems.

The difficulty of obtaining a satisfactory device for this purpose has led engineers to use fuses or excess current cutouts in many positions where they are generally useless, and are often an unnecessary source of danger. For instance, where alternating current generators have been arranged to work in parallel, it has been usual to insert fuses between each of these generators and the 'bus bars they feed. The result of this has been that if one of, say, three generators connected in parallel has failed, the remaining two generators have had to take up the load of the faulty one, and have in addition had to supply the current necessary to blow the faulty one's fuse; consequently, they have invariably blown their own fuses, and the entire supply has been interrupted. The usual method of dealing with this difficulty has been to increase the carrying capacity of the fuses to such an extent as to ensure their never blowing. In other words, the fuses have been practically done away with; but the very fact

that they were included in the original design of the board has of necessity added useless complication.

If, as has been shown, a fuse cannot be relied upon to isolate a faulty generator from the remainder of the system, it does not appear that it can serve any useful purpose. It is certainly not necessary to prevent the generators from being overloaded by a short circuit in any other part of the system, as all alternating current generators now on the market will stand short circuiting for a short time without injury, and it is evident that the proper fuse to blow on a short circuit on any feeder is the fuse actually protecting the faulty feeder. Should one of the generator fuses blow before the feeder fuse, the fuses of the remaining generators, coupled up at the time, would immediately follow suit, and consequently the total supply would be interrupted, and there would be nothing to indicate which feeder was faulty.[1] That the uselessness of fuses in this position is beginning to be recognised is evident from the following extract from Mr Clothier's paper on "High-Tension Switchgears."[2] Mr Clothier says in the conclusion of his paper:—

> "There is no doubt that it is the best practice to supply fuses with duplicate contacts to each phase on the feeder panels. But for the generators the conditions are different; with two or three alternators running in parallel, *fuses have sometimes given trouble by opening the circuit of all the machines when a fault has occurred on one only*. Reverse current automatic switches have been made to meet this objection, but complications are involved thereby, which introduce an element of uncertainty in action under emergencies. Another way of dealing with the question *is to have no fuses or automatic devices on the generators*. Modern alternators will stand a short for a few minutes, or at least for sufficient time to blow the feeder fuse, if the fault is on the mains, or if the fault is on the generator, to enable the attendant to isolate the defect."

And in the reply to the discussion on the paper referred to, Mr Clothier adds:—

> "Fuses are indispensable on high-tension feeders, but on modern machines they can be avoided; for the large alternating current generators in particular it is feasible to do without either fuses or any other automatic device."

It is true that, in a generating station where the switchgear is always under the immediate control of an attendant, automatic cutouts would

[1] Since the above was written, many authors of papers read in this country, on the Continent, and in the United States have condemned the use of fuses on generator circuits, and have recommended the use of reverse current circuit-breakers or of current direction indicators.

[2] *Proc. Inst. Elect. Engineers*, vol. xxxi. p. 162.

not be so necessary if there were anything to indicate to the attendant which switch to open in the event of one of the generators failing. In some direct-current stations the switchboards are equipped with central zero ammeters, and these serve to indicate which generator is failing, but in alternating-current systems, if an alternator fails, due, for instance, to a faulty connection in the field circuit, the failing machine short circuits the other generators running at the time, and the ammeters of all the generators in use immediately go over to their maximum reading; the attendant has therefore absolutely nothing to guide him as to which machine he is to switch out, and he is consequently liable to switch out a sound generator instead of the faulty one. If some indicating device corresponding to the central zero ammeter used in connection with direct-current systems were used for alternating-current work, the necessity of using an automatic cutout in circuit with the main generators would not be so apparent. Indicating devices for this purpose are referred to later in this chapter.

If an automatic device of any description is used, it appears that an apparatus is required that will on no account cut off a generator so long as it is supplying current to the 'bus bars, but will immediately disconnect any generator which fails to maintain its supply, and becomes instead a load on the rest of the system.

It is evidently incorrect to term a device used for this purpose in connection with alternating-current systems a return current or reverse current device, as the current under normal conditions has its direction reversed twice during every complete period. In an early paper by the author[1] on this subject, the word 'discriminating' was used to denote a cutout or other piece of apparatus that was capable of discriminating between a generating or motoring alternating current, and as no better word has been suggested it is adopted here.

Mr J. S. Raworth appears to have been the first engineer to take any practical steps towards overcoming the difficulties referred to above. In 1892 he invented the very ingenious discriminating fuse shown in fig. 91. The fusible conductor F is shunted by a switch S, and the secondary winding of a small transformer $T^2$. The switch is normally held in a closed position by the fuse, and the melting of the fuse allows the switch to open. The primary winding $T^1$ of this transformer is connected directly across the main 'bus bars, and it is so coupled up that the E.M.F. of its secondary winding is normally in such a direction as to tend to prevent the main current flowing through the fuse. For instance, during one half period the flow of current throughout the whole system will be in the direction indicated by the arrow-heads, and during the following half period it will be in the opposite direction. Now let it be supposed that the generator G

[1] *Proc. Inst. Elect. Engineers*, vol. xxvii. p. 490.

suddenly fails to maintain its supply. Current will then flow into it from the 'bus bars—that is to say, in the opposite direction to that indicated by the arrow-heads. The direction of the flow of current into the transformer will, however, be unaffected, and as a consequence the E.M.F. of the secondary winding of the transformer will be in the direction shown by the arrow; that is to say, its tendency will be to cause the current to avoid the path through the secondary winding and switch, and to flow instead through the fuse. The effect of this should be to melt the fuse at once and allow the switch to open and completely break the circuit.

The device referred to above appeared at first sight to be so simple that there seemed no doubt that the difficulty had been solved. It was found, however, on putting the apparatus into practice, that the solution was not so easily attained.

One of the difficulties that arose may be briefly indicated. It is evident that when there is no current flowing from the generator to the 'bus bars there will still be a certain amount of current flowing round the closed secondary circuit of the small transformer, and consequently through the fuse. This fuse must, therefore, be stout enough to carry this current without excessive heating, and, as a consequence, a very heavy motoring current is required to blow the fuse in the event of the generator failing. A number of experiments were made to endeavour to overcome this and other difficulties, but without success, and therefore the device was finally abandoned.

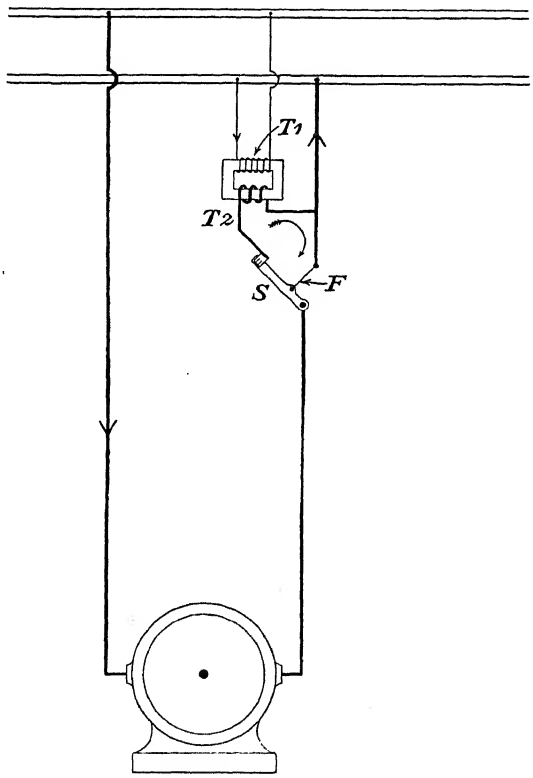


FIG. 91.—Raworth discriminating cutout for alternating currents.

About this time it occurred to the author that the problem might be solved magnetically by means of a compound wound device, depending

for its action upon a displacement of phase between the series and shunt windings.

Let the current curve I, fig. 92, represent the variations of the current during each period in the series winding, and let the E.M.F. curve E represent the variations of the current in the shunt winding, and let the dotted curve W represent the work done by the combined currents in the series and shunt windings. So long as the two curves are in phase with each other, as they will be when the dynamo controlled is acting as a

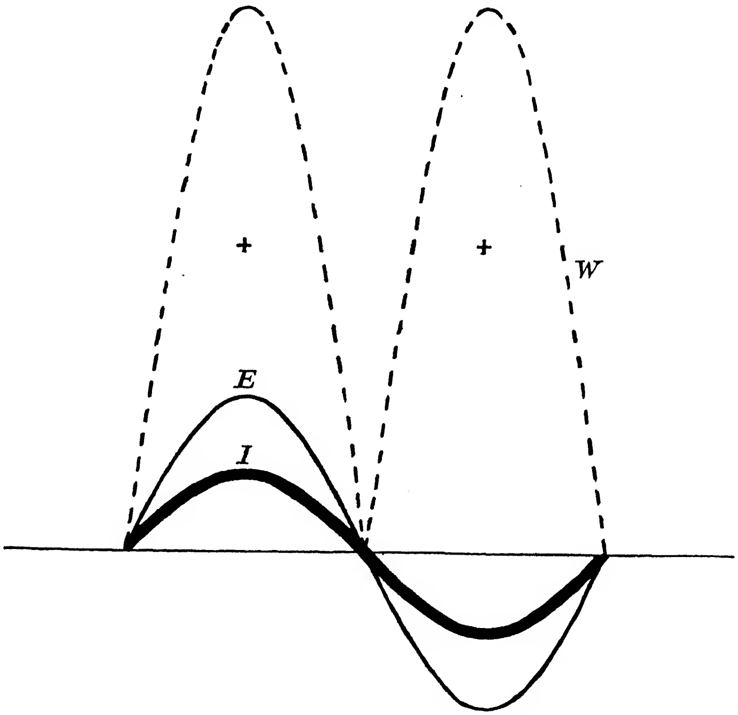



FIG. 92.—Curves illustrating theory of magnetically operated discriminating cutout.

generator, the work done will be entirely positive, and may obviously be applied to hold a catch controlling an automatic cutout in its closed position. Should, however, the generator fail, the current in the series winding will tend to drop approximately 180 degrees out of phase with the E.M.F. or current in the shunt winding. The work done by these combined magnetic forces will now be entirely negative, or in the opposite direction, as shown in fig. 93. This force may now be applied to move the catch referred to above in an opposite direction; *e.g.*, it may now be made to release the catch, thus allowing the cutout to open and disconnect the faulty generator.

The application of the original idea appeared at first sight to be a very simple matter; but a full account of the difficulties that have had to be overcome would of itself fill a good-sized volume. A brief description of some of the most troublesome may, however, be of interest.

The first practical application that was tried is shown in fig. 94. This consists of a solenoid wound with a thick winding, which is connected in series with the leads between the generator and the main 'bus bars, and a shunt winding connected across the secondary winding of a small trans-

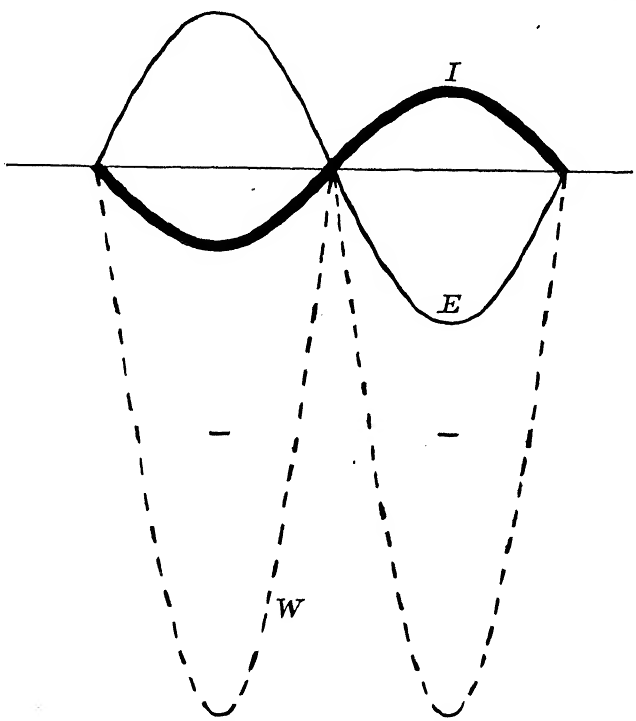



FIG. 93.—Curves showing reversed pull due to series current being out of phase with E.M.F.

former, the primary of which is across the main 'bus bars. The direction of the current throughout the whole system will, under normal conditions, for one half period be in the direction shown by the arrow-heads; whereas during the following half period the direction will be reversed in both the series and shunt windings. That is to say, in each case the current in the series winding will be opposed by the current in the shunt winding, and there will therefore be little or no magnetic attraction upon the core C. This will consequently tend by gravity to keep the catch controlling the switch in its closed position. Should, however, the generator controlled

by this cutout fail, the direction of the current in the series winding will be reversed relatively to the direction of the current in the shunt winding, since the latter will be unaffected by the failure of any generator; consequently the two currents will combine to produce a magnetic field in the same direction, the core will be lifted and the catch released, thus allowing the switch to open and cut off the faulty generator. The tendency of the shunt current under normal conditions is to counteract the

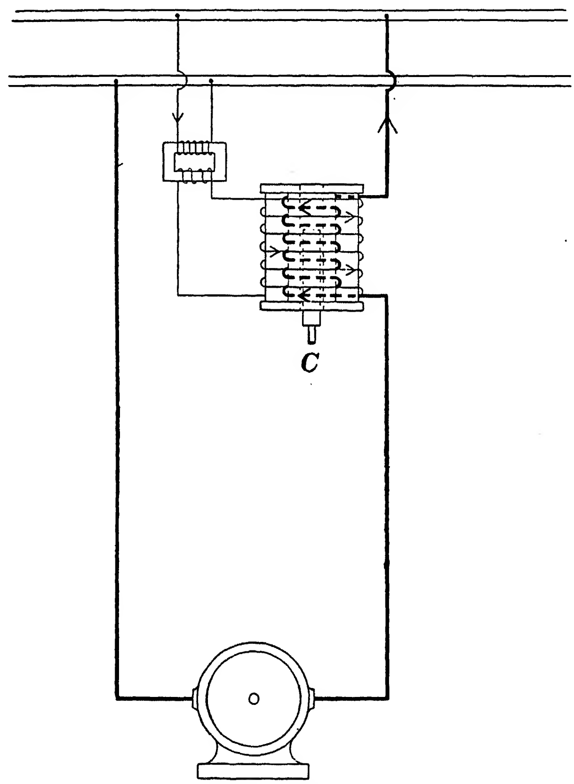



FIG. 94.—A simple magnetically operated discriminating cutout release.

effect of the series current for any load within reasonable limits, for as the series current increases, the self-induction of the shunt current is counteracted, and this consequently tends to increase almost in the same proportion. It was found, however, that when a short circuit occurred on the mains the current in the series winding increased to such an extent that the current in the shunt winding was quite unable to counteract its effect, and all the generators were cut out of circuit, so that the protection was little, if any, better than could be obtained by fuses. This device was therefore also abandoned.

The difficulty referred to above was ultimately overcome by a differential shunt winding, as shown in fig. 95. It will be seen that the arrangement here is exactly similar to that shown in fig. 94, except that the bottom half of the shunt winding is wound in a reverse direction to the top half, and the normal position of the core is in the centre of the coil. It will be evident that a heavy current in the series winding alone will have a tendency to pull the core into the centre of the coil; but this is its normal position,

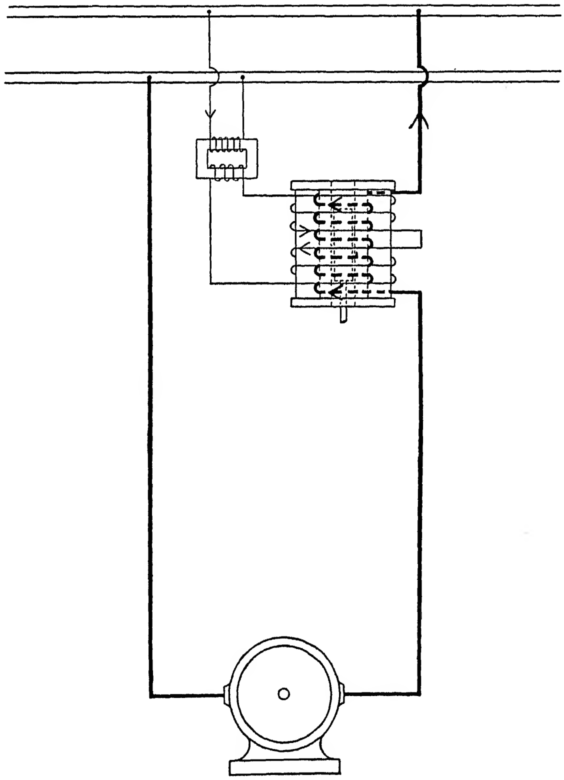


Fig. 95.—An improved discriminating release.

consequently it will not be moved. On the other hand, while the result of the current flowing through the top half of the shunt winding is to pull the core up, that of the current in the bottom half is to pull it down, and these two forces being exactly counterbalanced, there will be no movement due to the shunt winding alone. When, however, a heavy generating current is flowing through the series winding, with the shunt winding connected up as shown, the effect of this current will be to assist the shunt winding in the bottom half of the coil and to oppose it in the top half. The result will be that the field below the centre of the coil is strengthened,

while that above the centre is weakened; the core is therefore pulled down, and its tendency is to lock the catch holding the switch in a closed position.

Should the generator fail, the current in the series winding will be reversed relatively to that in the shunt winding, the field above the centre of the coil will in consequence be strengthened, and that below the centre will be weakened. The core will, therefore, be pulled up and the switch released.

This latter device has been in continuous use for the past eight years, and its behaviour has proved it to be absolutely reliable under all conditions.

A device of this description, to afford the best protection, should operate with a moderately small motoring current, as it will not then throw so

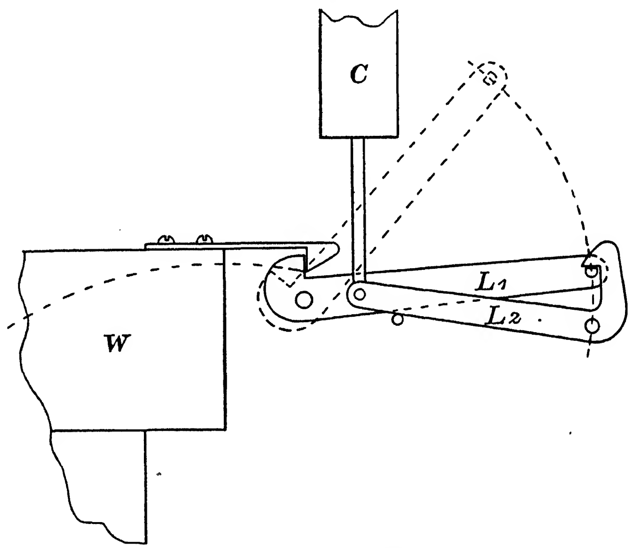



FIG. 96.—A simple and reliable catch.

heavy a strain upon the remaining generators. The operating current should certainly not exceed 25 per cent. of the normal maximum generating current. This means that the magnetic pull is very slight, and consequently it becomes necessary to use the device referred to above as a relay to close a local operating circuit, or to employ a very sensitive catch. Both systems have their advantages. If, however, a catch alone is used, it is necessary to so construct it that, in addition to being sensitive, it shall under no conditions operate unless the core attached to it is pulled up. Fig. 96 shows an arrangement that has been found to be quite reliable in this respect. It consists, as will be seen, of two small levers. The pressure of the weight W on the lever $L^1$ tends to move this lever into the dotted position shown. This movement is, however, prevented by a catch

on a second lever $L^2$. The relative position of the two levers is such that the arc described by the movement of the pin at the tail end of the lever $L^1$ exactly cuts the fulcrum of the lever $L^2$. The consequence is, no amount of increased pressure on the weight W will tend to move the core C up or down. It will be evident that, if the fulcrum of the second lever was set a little to the right of its correct position, the pressure due to the

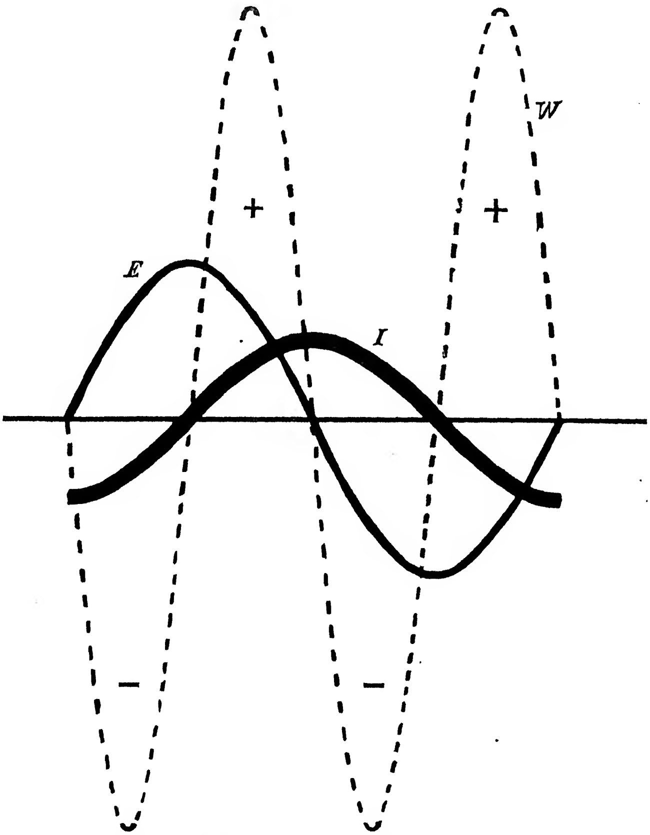



FIG. 97.—Curves showing equal cutting-out and holding-in pulls due to a phase displacement of 90°.

weight W would tend to lift the core, and consequently the catch would be liable to be released by vibration. If, on the other hand, it was set too much to the left, it would tend to pull the core down, and this pull would have to be overcome by the magnetic attraction of the solenoid before the switch was released, and consequently the cutout would require a much bigger return current to operate it.

It has been mentioned above that the device illustrated in fig. 95 has never been known to fail to operate when the current in the series winding

dropped approximately 180 degrees out of phase with the current in the shunt winding. Conditions have, however, been met with in which this phase displacement does not take place when a generator fails. It has been found, for instance, that the phase displacement on opening the field circuit of a generator is totally different from the displacement that occurs when the engine or other prime mover fails, and the exciting current of the generator is maintained normal. Experience has shown that a coil wound to give the best results under the latter conditions absolutely fails to operate when the field circuit is broken. This failure is due to the fact that the two currents are only approximately 90 degrees out of phase with each other, and as a consequence the effect obtained is practically that shown in fig. 97. It will be seen that the pull is alternately and equally

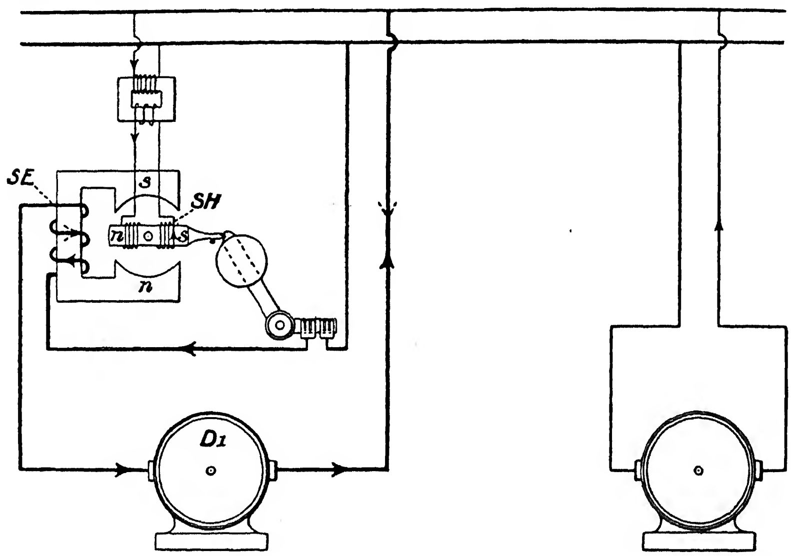



FIG. 98.—Shunt wound motor type of cutout release.

positive and negative, and consequently the tendency to move the plunger is eliminated during each alternate half period. This difficulty has been overcome by inserting sufficient inductive resistance in the shunt circuit to give the best results under either of the conditions met with. The device has been of necessity rendered less sensitive than when adjusted for either one of the conditions mentioned, but no difficulty has been experienced in getting a point at which it could be relied upon to operate under either of the conditions.

Although the solenoidal type of release referred to above has always been found reliable, it was considered somewhat cumbersome, and was not an ideal shape to apply to some types of magnetic cutouts. It was felt that a smaller and neater device to serve the same purpose might be

obtained by using a practically closed magnetic circuit. Such an arrangement is shown diagrammatically in fig. 98. It will be seen that this is to all intents and purposes a shunt wound motor. When the current in the series winding is in phase with the current in the shunt winding, the armature tends to turn in one direction against a stop. The torque in this direction is arranged to securely lock the switch in the closed position, and it will be obvious that the heavier the generating current the more securely will the switch be locked. When the current in the series winding drops sufficiently out of phase with the current in the shunt winding, the armature rotates in the opposite direction, and so releases the catch supporting the controlling weight of the switch.

A number of cutouts have been made to operate on this principle, particularly for use with direct currents. The cutout illustrated in fig. 99 is controlled by a release of the type illustrated in fig. 98.

One drawback to the arrangement has been the necessity of using brushes and collector rings, or flexible connections to conduct the current to the shunt winding on the armature. Although this was not a serious defect, it was considered that connections of this sort should be avoided if possible, and consequently attention was turned to designing a release gear having both series and shunt windings stationary.

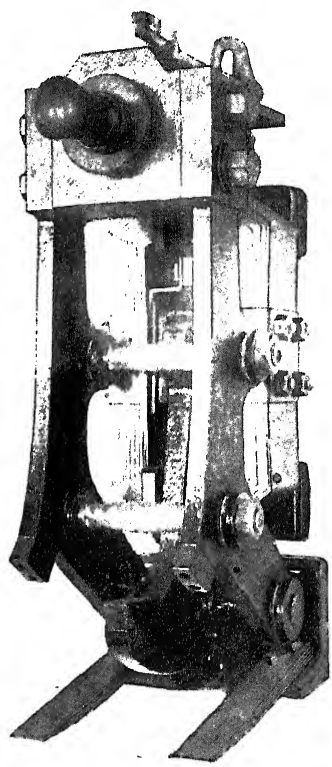


FIG. 99.—A 4000-ampere discriminating cutout.

A sectional view of a device of this description is shown in fig. 100, and fig. 101 gives a perspective view of the various parts unassembled. It will be seen that the series winding consists of a simple casting. This is surrounded by three pieces of sheet-iron formed into channels, which serve as the field magnet. The armature consists of two similar pieces of channel iron, and the shunt winding surrounds one leg of this, but is not mounted directly on the iron, so that the armature is free to move, whilst the shunt winding is stationary. When the current in the series winding is in phase with the current in the shunt winding, the polarity of the various poles will be as indicated by the letters N and S, and consequently there will be a combined torque, due to the attraction and

repulsion of the various poles, in a direction tending to lock the catch holding the switch in its closed position. Upon reversal of the current in the series winding relatively to that in the shunt winding the polarity of the

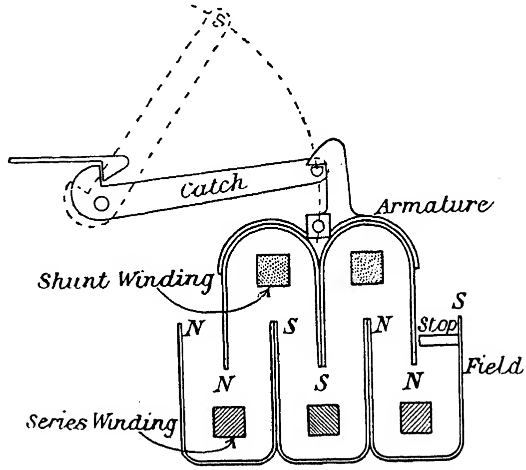



FIG. 100.—Section of multiple pole release.

field will be reversed relatively to that of the armature, and consequently the armature will be attracted in the opposite direction, and will thus release the catch supporting the weight of the cutout. Precisely the same device may be used for direct or alternating currents, and it is

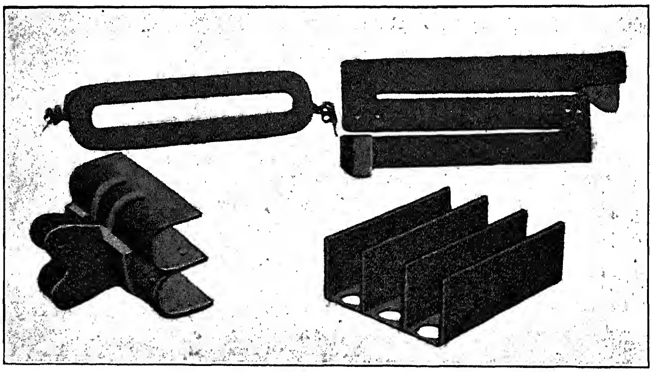


FIG. 101.—Unassembled parts of multiple pole release for discriminating cutouts.

exceedingly powerful for its size. A number of cutouts of this type have been made to operate with a direct current of less than 30 amperes in the series winding, and as the latter consists of only one and a half turns, this means less than 45 ampere turns.

A somewhat similar device to that shown in fig. 100 is illustrated diagrammatically in fig. 102, and in perspective in fig. 103, used as a discriminating relay. A swinging iron armature A is hung from a fulcrum B. This is magnetised by a shunt winding C. The free ends of the armature, bent in the form of an anchor, are surrounded by the series winding. So long as the series current is in phase with the shunt current, the armature is pulled against the stop F¹. Should the series current be reversed relatively to the shunt current, the armature will be attracted towards, and will make connection with, the contact F², thus completing the local

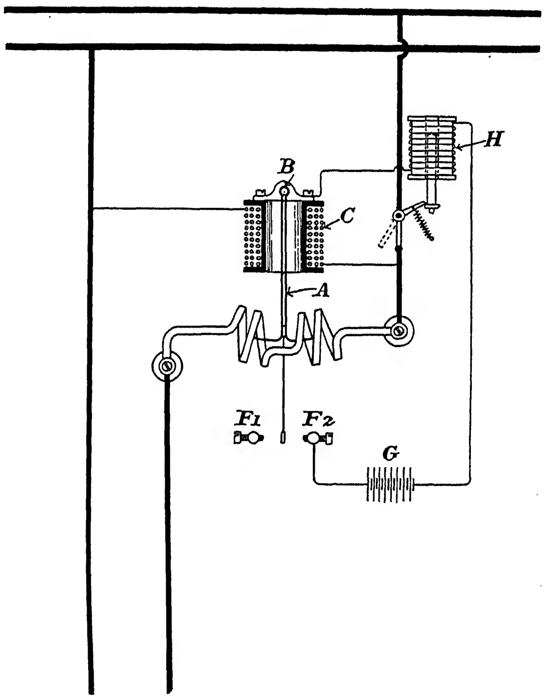



FIG. 102.—Diagram of discriminating relay.

circuit through the battery G, and release winding of the cutout H. This relay may also be used on direct or alternating current circuits.

Reference has been made to the use of discriminating cutouts for alternating current primary generators only. It is evident, however, that similar remarks *re* the uselessness of fuses apply to an equal extent to secondary generators or transformers. What alternating current engineer has not suffered the experience of a complete interruption to the supply due to a short-circuited transformer in a sub-station blowing the fuses of all the other transformers coupled in parallel with it?

In the United States this difficulty has been thoroughly appreciated,

and the various recommendations contained in the author's I.E.E. paper on "The Prevention of Interruptions to Electricity Supply"[1] have been generally adopted. That is to say, discriminating cutouts are used instead of excess current cutouts where generators or transformers are coupled in parallel to feed common 'bus bars.

In connection with the generators at the Metropolitan Street Railway Company's station at 96th Street, New York, no automatic cutouts of any description are used for directly controlling the main generators, but a discriminating cutout relay is placed in series with each generator, and this is connected up to close a local lamp circuit, which serves to indicate

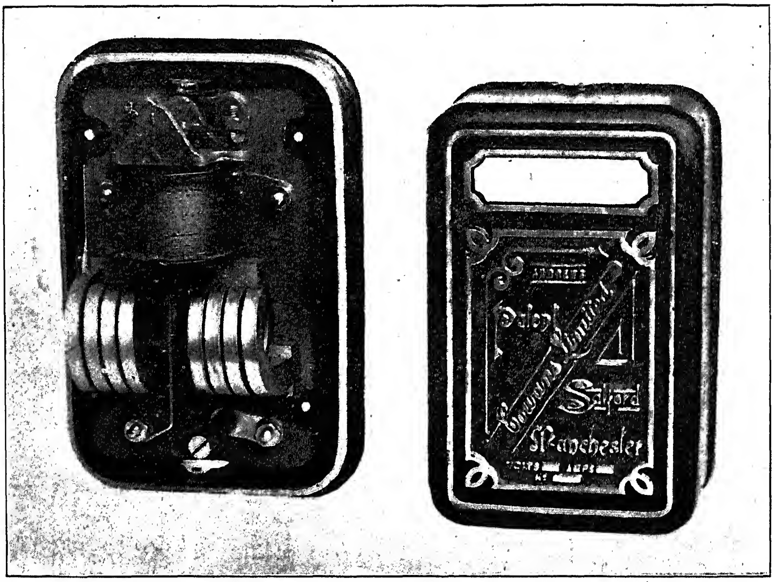



Fig. 103.—A simple discriminating relay.

to the switchboard attendant which generator has failed, the indicating lamps being placed in close proximity to the operating lever of the switch controlling that particular generator. This appears to be a very reasonable modification of the original system proposed, for dealing with cases where satisfactory hand operated switchgear is in use, and it is not felt desirable to face the radical alterations that would be entailed in modifying such switchgear to be operated automatically.

The discriminating indicating device used by the Metropolitan Street Railway Co. appears, however, to be an unnecessarily complicated arrangement; added to which, it gives no positive indication under normal

[1] *Proc. Inst. Elect. Engineers*, vol. xxvii.

conditions. This may mean that, on the very rare occasions when the failure of a generator should cause it to act, it may be out of working order. It appears that the device, to be satisfactory, should be provided with two lamps—one being red and the other green. So long as the generators are all working properly, the green lamp only should be incandesced. Should a generator fail, the current direction indicator connected in series with that particular machine should extinguish its green light and show a red light.

The author has recently designed a device that effects this object in a very simple manner and without any moving parts. This device consists of a small transformer provided with two secondary windings, a red and a green lamp being connected respectively across the terminals of these. The connections of this transformer are illustrated in fig. 104. It will be seen that, in addition to the winding D in series with the generator, a second primary winding which is connected across the main 'bus bars, or across any low-tension circuit supplied from these 'bus bars, is wound upon the outer limb of this transformer. The effect of this shunt winding is to cause a flux to circulate in the transformer in the direction shown by the thin arrows, and the flux due to the series winding in that shown by the thick arrows. Under normal conditions these two fluxes oppose each other in the magnetic circuit enclosed by the secondary winding connected to the red lamp, and assist each other through the secondary winding connected to the green lamp; consequently the green lamp is lighted and the red lamp extinguished. Should the generator fail, the direction of the flux due to the series winding relatively to that due to the shunt winding will be reversed, and consequently the green lamp will be extinguished and the red lamp lighted.

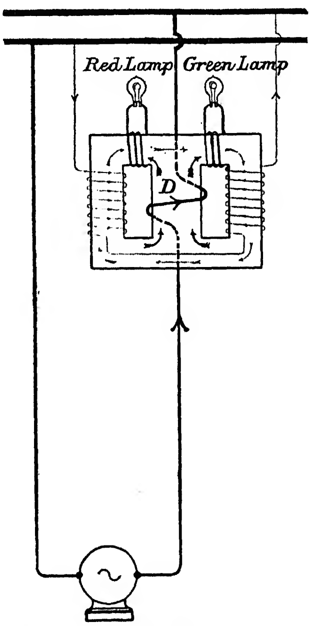



Fig. 104.—Diagram of current direction indicator.

Fig. 105 shows one of these current direction indicators fitted into the pot provided with tongues to fit into the fuse contacts of a Ferranti switchboard. This forms a simple arrangement in cases where fuses are not required in the generator panels.

Another modification of this device is shown in fig. 106. This transformer requires no series winding; the conductor carrying the series current is merely threaded through the micanite tube in the manner shown.

The secondary windings of the discriminating transformer referred to above may obviously be used to excite any differential device for operating an automatic cutout.

A device suitable for this purpose is shown in fig. 107. This, it will be seen, consists of a double wound coil, the two windings of which may be connected respectively across the two secondary windings of the discriminating transformer. An iron core or plunger rests on a stop in a position midway between the two coils. The connections are so arranged that when the series winding of the discriminating transformer is carrying a generating current the magnetic field in the lower winding of the double

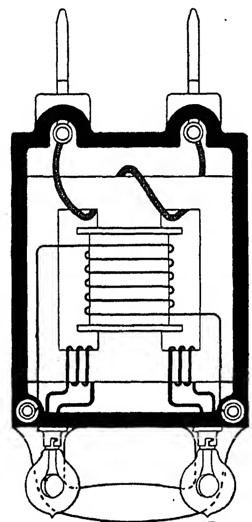



FIG. 105.—Current direction indicator constructed to fit Ferranti fuse contacts.

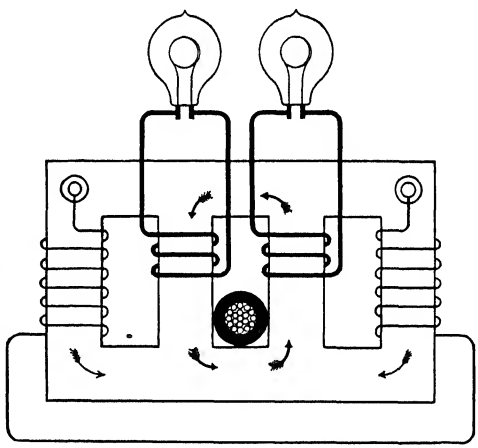


FIG. 106.—Current direction indicator having no series winding.

wound coil will be more powerful than the field in the upper winding. Upon the current in the series winding of the transformer becoming reversed relatively to the shunt winding, the field in the upper winding will be strengthened, whereas that of the lower will be weakened. This will lift the core off its stop, and upon rising it will hit the end of the catch a smart blow, and so release the cutout.

A further application of discriminating cutouts, which has been taken up fairly extensively in the States, and in connection with three or four undertakings in this country, is that of using such cutouts for the protection of duplicate feeders.

It is well known that where feeders are coupled up in parallel to feed a common distributing centre, it is useless to attempt to protect them with

fuses, as shown in fig. 108, with the idea that, in the event of a fault occurring on either feeder, the fuses at both ends of the faulty feeder will be blown, and the supply maintained through the remaining feeder. Should a short circuit occur at $E_1$, the fuse at $F_1$ will undoubtedly be blown first. The current will then be fed to the short through the fuses $F_2$, $F_3$, and $F_4$; but it is obvious that fuses $F_2$ and $F_3$ will have to carry the

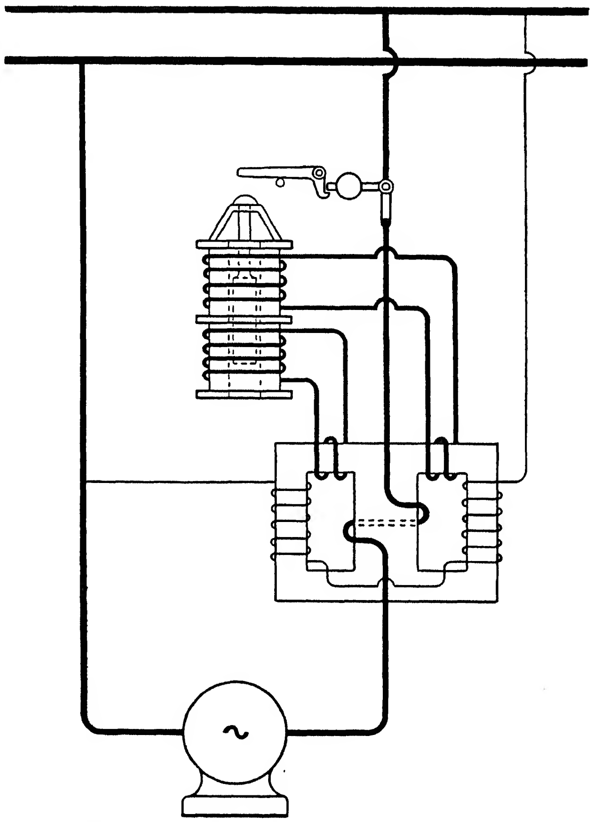


FIG. 107.—Diagram illustrating method of operating generator cutouts by current direction indicator.

current necessary to blow the fuse $F_4$, in addition to any load that may be on at the time. The result is, one of the fuses on the sound feeder is certain to be blown before the fuse on the distributing end of the faulty feeder, and consequently the entire supply to this distributing centre will be interrupted.

It occurred to the author some years ago that this difficulty might be overcome by using discriminating cutouts in place of the fuses $F_3$ and $F_4$. It is evident that under normal conditions the current in the series

windings of both cutouts will be approximately in phase with the E.M.F., and consequently the torque of the releasing device of each cutout will tend to maintain the cutout in its closed position. Should, however, a short circuit occur on either feeder, the current in the series winding of the cutout controlling that feeder will drop approximately 180 degrees behind the current in the shunt winding, but there will be no serious displacement of phase in the current through the cutout controlling the sound feeder.

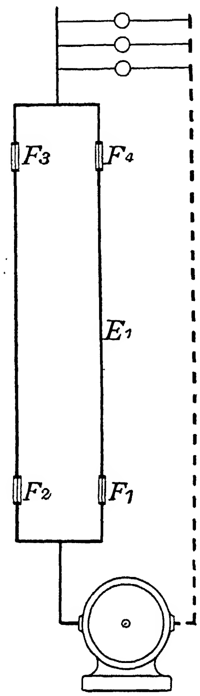



FIG. 108.—Diagram illustrating uselessness of attempting to protect duplicate feeders with fuses.

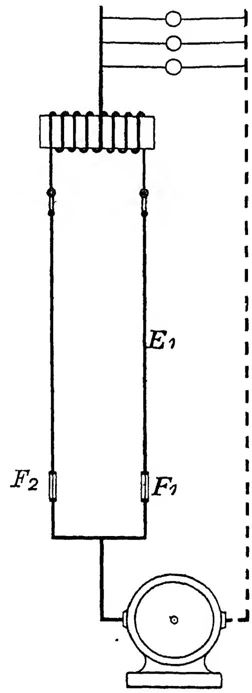



FIG. 109.—Choking coil protection of duplicate feeders.

As a consequence the cutout on the faulty feeder will operate, and so disconnect the fault from the system at the distributing end.

It was found, in attempting to carry out this idea, that an apparently insurmountable difficulty had to be dealt with, which did not arise in the use of these cutouts for the control of primary or secondary generators. If a low-resistance fault occurs in either feeder, the drop of pressure due to the current in the other feeder becomes so great as to render the action of the discriminating cutout on the faulty feeder unreliable. This difficulty is particularly noticeable when generators with a big armature drop are used.

In consequence of the above, the author has recently abandoned the use of discriminating cutouts for the protection of single phase alternating

current duplicate feeders, and has adopted instead a totally different device, the operation of which is entirely unaffected by any drop of pressure due to $C^2R$ losses.

The most important factor in this protective arrangement is a discriminating choking coil—that is to say, a choking coil which has no reactive effect under normal conditions, but, in the event of either feeder breaking down, becomes a highly inductive resistance between the faulty main and the sound one, and thus prevents an excessive current passing from one to the other. The scheme is shown diagrammatically in fig. 109. It will be seen that the arrangement of feeders is similar to that shown in fig. 108—that is to say, duplicate feeders are coupled in parallel at the generating station end, and at the distributing end. At the latter point, however, a choking coil is connected between the two feeders, and the supply to the distributing point is taken off from the centre of this coil. It will be obvious that under normal conditions the load will be divided equally between the two feeders, and consequently the iron in the choking coil will tend to be magnetised in one direction by the current from the one feeder, and in the opposite direction by the current from the other feeder. The result will be, the two halves of the choking coil will exactly neutralise each other, and there will be no inductive drop due to the reaction of this coil. The only drop will be that due to the $C^2R$ losses in the windings, which can be kept very small. Should a short circuit occur between either one of the feeders and earth, say at $E_1$, the fuse $F_1$ will be blown, *i.e.* that fuse directly between the fault and the generating station. Current will then tend to return to the short circuit from the other feeder, *via* the discriminating choking coil; but the whole of this current will magnetise the coil in one direction, and there will be no demagnetising effect. Consequently, the choking coil will become a highly inductive resistance, and will prevent an excessive current passing to the short circuit.

In cases where the distributing centre is in charge of an attendant, the only apparatus necessary, in addition to the choking coil, is a switch on each feeder and a pressure-indicating device. If a short circuit occurs on either feeder, the indicator connected to it will fall to zero, whereas the indicator on the sound feeder will remain normal. The attendant will, therefore, merely have to switch off the faulty feeder.

One very important feature in connection with this device is that the switches at the distributing ends of the feeders under no conditions have to break a heavy current, added to which, the sound feeder is never required to carry the heavy short circuit current due to a fault on its neighbour. The result is, the risk of a failure on one feeder causing a break-down on the other, as often occurs in cases where feeders are coupled in parallel in the ordinary way, is entirely prevented. The extent to which the current

to the short circuit is choked down will, of course, depend entirely upon the size of the choking coil. This, however, need not be large, as it has been found that a coil occupying the space of a 6 kilo-watt transformer, when wound with a conductor large enough to feed a 100 kilo-watt 2000 volt sub-station, will, at a periodicity of 100$\sim$, choke down the current due to a short circuit on either of the feeders to about 3 amperes.

The experiment has been tried of short-circuiting the feeder $E_1$, fig. 109, when $F_1$ was fused to carry 150 amperes, and $F_2$ to carry only 10 amperes, and it has been found that, although the current through the short circuit has been sufficiently heavy to immediately blow $F_1$, the choking coil has prevented sufficient current from flowing back to the fault, *via* the sound feeder, to blow the very small fuse $F_2$.

It will appear, on reference to fig. 109, that when the faulty feeder is disconnected from the choking coil the whole of the current to the sub-station will be fed through one half of the coil only, and as this is unbalanced by a current in the opposite direction, it is necessary to either short circuit the coil or to divert half of the current from the sound feeder through the opposite side of the choking coil. This may be done by an independent short-circuiting switch, or by means of cross connections to the switches between the feeders and the choking coil, as indicated in fig. 110. The latter arrangement has the advantage that everything is done by the one operation of opening the switch on the faulty feeder. If, for instance, a fault occurs at $L^1$, the fuse $F^1$ will be blown, and the supply will be continued through feeder B only, and one half of the coil. If the switch $S^1$ is now thrown over to the contact connected to B, the current from B will divide between the two halves of the choking coil, and this will again become non-inductive.

In cases where it is desired to effect the switching operation, referred to above, automatically instead of by an attendant, it may be done in various ways. One of the earliest methods is shown diagrammatically in fig. 111. A differential static voltmeter V is connected between the feeders A and B. This voltmeter has a central swinging disc, which is earthed. This swinging disc normally hangs midway between two outer plates, which are respectively connected to the mains A and B by way of the primary coils of two small transformers $T^1$ and $T^2$. The secondaries of these transformers are made for a low pressure, each secondary being short circuited by a copper fuse wire which normally holds up a switch in the manner shown in the diagram. So long as the conditions are normal, the middle disc of the voltmeter V hangs clear of the two outer plates; should, however, one of the mains, say A, become short circuited, the attraction between the movable disc and the two outer discs will become unbalanced, and consequently the feeder B will be connected to earth through the voltmeter by way of the primary of the transformer $T^2$. A very small current is

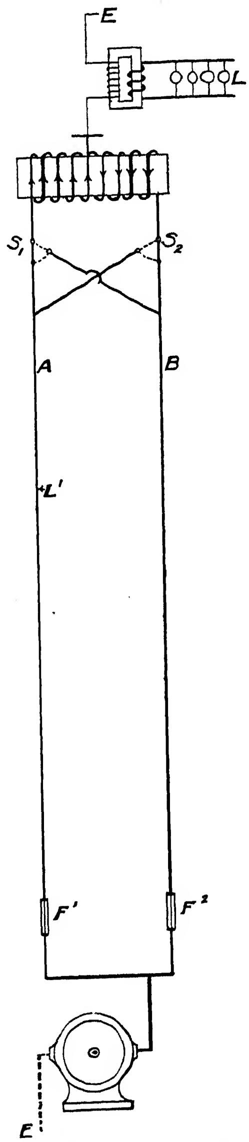



FIG. 110.—Diagram illustrating method of maintaining choking coil non-inductive, when working on one feeder only.

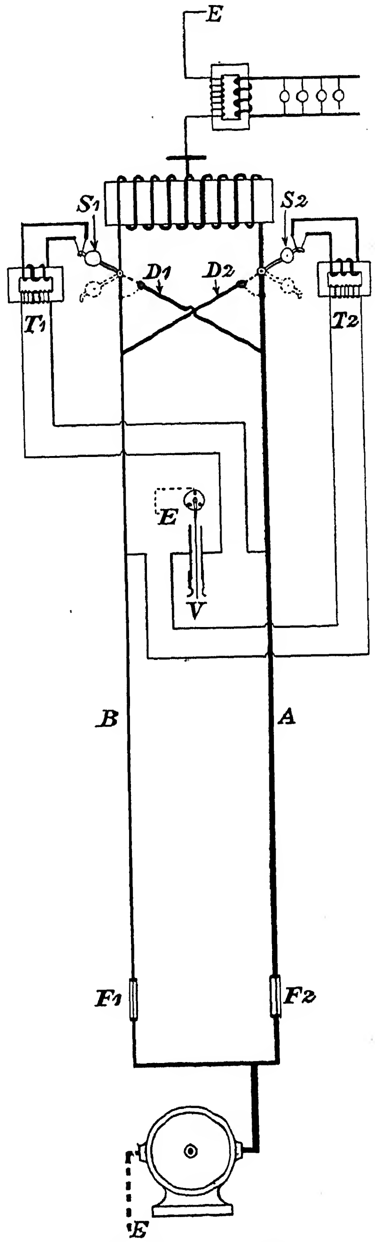



FIG. 111.—Method of operating cutouts, and protecting duplicate feeders, by static relays.

thus sent through the primary of $T^2$, which induces a very much larger current in the secondary of $T^2$, melts the fuse, and allows the switch $S^2$ to throw over to $D^2$, cutting off the main A at the sub-station end, and at the same time connecting this side of the choking coil to the sound main. The faulty main will also have been cut off at the generating station end by its fuse $F^2$.

The action already referred to with reference to fig. 110 has also taken place in this case as regards the action of the equaliser in introducing a

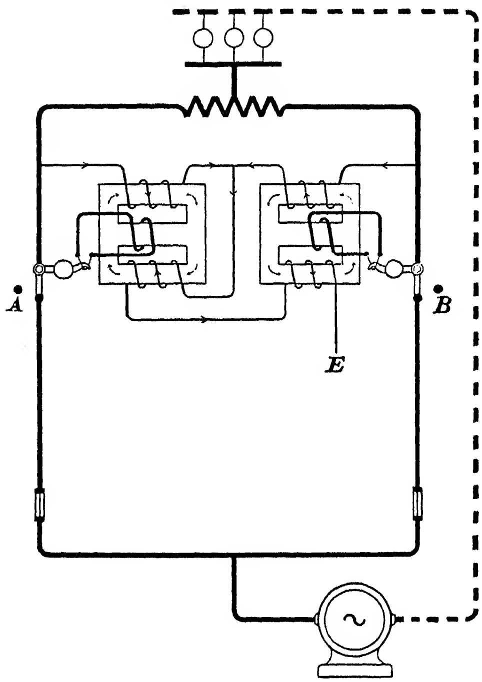



Fig. 112.—Another method of controlling duplicate feeder cutouts.

choking coil to prevent the interference with the fuse of the sound main B, as well as to prevent interruption of the supply to the load.

Although perfectly satisfactory results were obtained with the electrostatic device referred to above, it appeared too delicate a piece of apparatus for controlling switches that might in some cases be handling hundreds of horse-power. It was in consequence abandoned, and an attempt was made to operate the switches with a simple inductive device having no moving parts. This device is illustrated diagrammatically in figs. 112 and 113.

Two small transformers are connected up, as shown in the diagram, between the two high-tension feeders, the contacts A and B being cross-

connected to the feeders on the opposite side. Under normal conditions the current in these windings will flow in the direction shown by the arrow-heads; and this magnetising force will tend to cause a flux to circulate round the outer limbs of the transformers. There will obviously be no tendency for the flux to flow through the centre limb of the transformer, upon which the secondary winding connected across the copper fuse-wire supporting the weighted switch is wound. Should, however, one of the feeders break down, the two small transformers will be fed from the

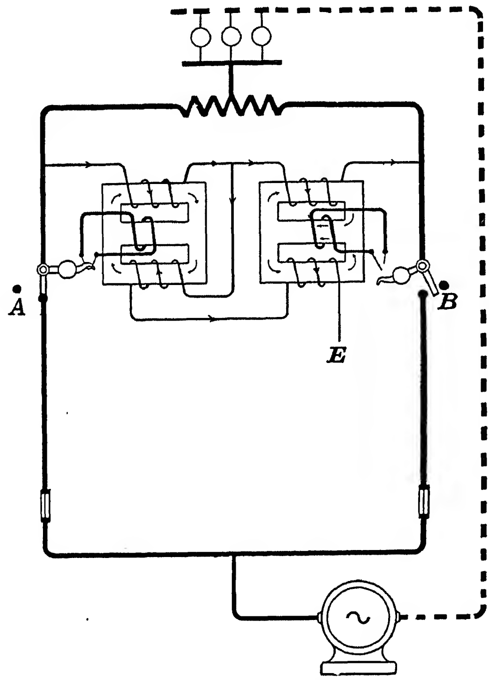



FIG. 113.—Diagram illustrating how current is induced in the secondary of a transformer controlling a faulty feeder.

remaining sound main only, and the direction of the current and resulting flux will be as shown in fig. 113. It will be seen that the flux in the transformer controlling the switch on the sound main remains as before, but in the other transformer the flux is diverted through the centre limb, and a heavy current is induced in the copper fuse supporting the weighted switch on the faulty main, thus causing this to open and instantly disconnect the fault, leaving the supply maintained at normal pressure through the healthy main. It will be obvious that under normal conditions the fuse has to carry no current, and consequently there is not the slightest risk of its deteriorating.

For controlling small switches this transformer release appeared to be

all that could be desired, but on attempting to apply the principle to the control of large heavy-current switches, magnetic leakage troubles crept in, and were apparently insurmountable.

The device finally adopted for the automatic control of these switches is very similar to the relay illustrated in figs. 102 and 103. The shunt winding C, fig. 102, of this apparatus is connected to any L.T. source of supply fed by the feeders to be protected; and the series windings are replaced by fine wires connected between the duplicate feeders. Under normal conditions there will be no difference of potential between these feeders, and consequently the armature A is only influenced by gravity; it hangs, therefore, in a central position between the contact studs $F^1$ $F^2$. Should either feeder fail, current will flow from the sound to the faulty feeder through the coils between the feeders, and this will cause the armature to be deflected to the left or right, according to which feeder fails, thus completing the circuit through contacts $F^1$ or $F^2$, and releasing the switch controlling the faulty feeder.

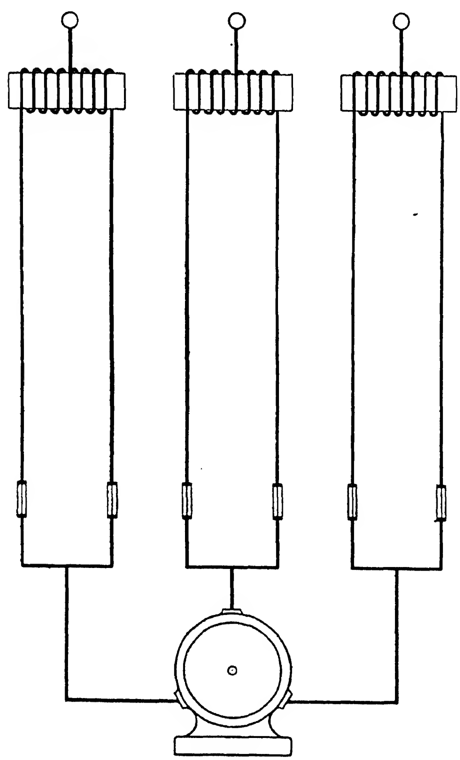


FIG. 114.—Discriminating choking coils for three-phase feeders.

Fig. 114 shows an application of discriminating choking coils for protecting three-phase duplicate feeders.

**Protection of any number of Duplicate Feeders by Discriminating Choking Coils.**—In cases where the number of feeders connected in parallel is an uneven one, the discriminating choking coil previously described cannot be used, as it is impossible to obtain a balance in the two halves of the coil. Mr Leonard Wilson, of the Stanley Manufacturing Co., U.S.A., has suggested a modified arrangement of discriminating choking coils which appears to meet this difficulty. This arrangement is illustrated in figs. 115 and 116.

Under normal conditions the current supplied to the 'bus bar A, fig. 115, at the distributing centre will be divided equally between the three or

more feeders and the windings of the choking coils $a^1$, $a^2$, and $a^3$. From A it will be conducted in series through the windings $b^1$, $b^2$, and $b^3$, and will therefore always equal the sum of the currents in the windings $a^1$, $a^2$, and $a^3$. The ratio of the turns in the $b$ windings to the turns in the $a$ windings is always as 1 to the number of transformers. It will be evident, therefore, that under normal conditions the choking coils will be non-inductive.

Now, should feeder 3, fig. 116, go to earth at E, it will blow fuse $F^3$,

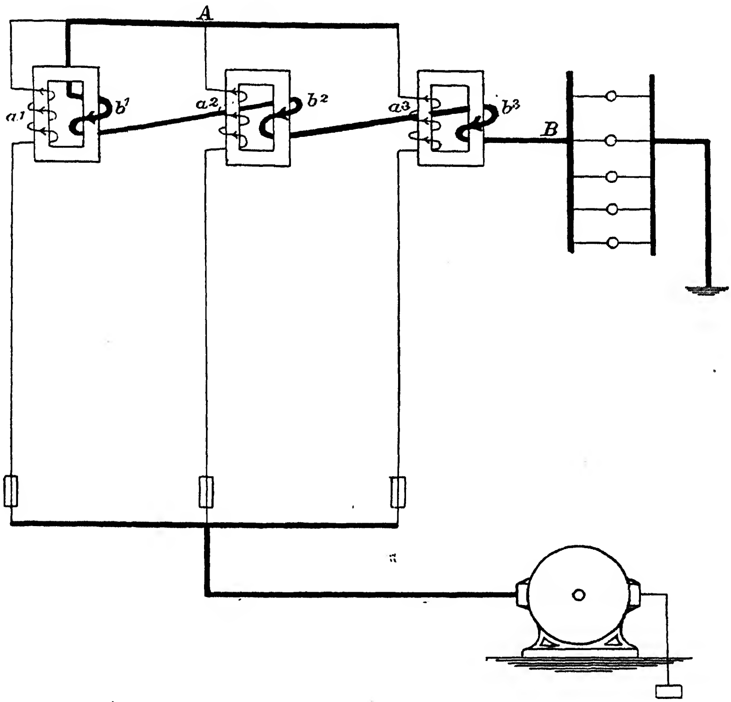



FIG. 115.—Method of protecting multiple feeders by discriminating choking coils.

and this feeder will fall to earth potential. Assuming the normal pressure to be 10,000 volts, the feeders 1 and 2 will be maintained at this potential, and these feeders will supply current through the choking coil windings $a^1$ and $a^2$ in parallel, and through $a^3$ in series with $a^1$ and $a^2$. The drop of pressure across $a^3$ will therefore be double the difference of potential across $a^1$ and $a^2$. But the current in the windings $a^1$ and $a^2$ will induce an E.M.F. in the windings $b^1$ and $b^2$, and this induced E.M.F. will in the case illustrated be equal to one-third of the drop of pressure across $a^1$ or $a^2$, and will be in such a direction as to increase the pressure of supply. The

current in winding $a^3$ will also induce an E.M.F. in the winding $b^3$, and as this induced E.M.F. is always equal and opposite to the sum of the E.M.F.'s induced in $b^1$ and $b^2$, the potential of the 'bus bar B will under all conditions be equal to the potential of the 'bus bar A. The drop of potential across

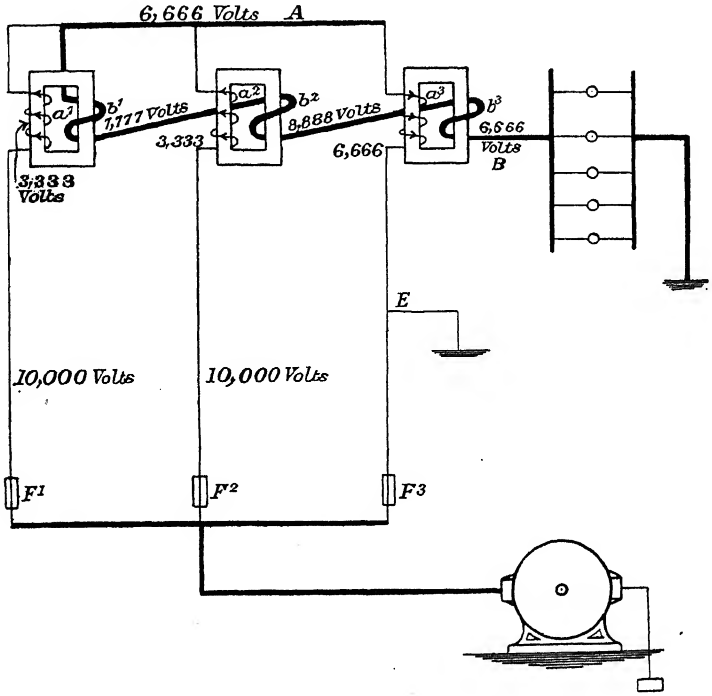



FIG. 116.—Method of protecting multiple feeders by discriminating choking coils.

the supply when one of the feeders is short circuited will in all cases depend upon the number of feeders and choking coils connected in parallel. Thus for three it will be 33·3 per cent.; for five, 20 per cent.; and for ten, 9 per cent.

Arrangements may of course be provided for automatically switching off the faulty feeder, as in the case of simple duplicate feeders.

# CHAPTER VI.

## ARRANGEMENT OF 'BUS BARS AND APPARATUS FOR PARALLEL RUNNING.

Obsolete system of running separate generators on separate feeders—Various methods of duplicating 'bus bars—Requirements to be fulfilled in duplicating 'bus bars—Examples of methods of duplicating or sectionising 'bus bars: 'Niagara,' 'Bertram,' 'Metropolitan Street Railway Company, New York,' and 'Hastings'—Paralleling devices—A crude and simple synchroniser—Ordinary synchroniser—Methods of connecting up synchronisers—Method of testing synchroniser connections—Rotary synchronisers: 'Ferranti' painted field magnets, 'Lincoln' and 'Edgcumbe' rotating pointers, 'Schuckert' rotating lamp, and another rotating lamp device—Aids to parallel running: Artificial load, choking coils, and automatic cutouts, all unnecessary for modern generators.

When the output of a generating station becomes greater than can be carried by one generator, it is necessary to provide means for throwing part of the load upon the other generators. At one time it was customary in many alternating current stations to divide the load up into sections, supplying the different sections from independent generators. This system involved a momentary interruption of the supply every time a section was switched over from one generator to another. The arrangement was also very inefficient, as it often entailed the necessity of running a number of generators for several hours each night partially loaded, and as a consequence the plant load factor was usually extremely low.

The difficulties of running alternators in parallel have now, however, been entirely overcome in practically all types of alternating current generators, and consequently the practice of running separate generators on separate feeders or groups of feeders has become practically obsolete. It is now the universal practice to run both generators and feeders in parallel. For this purpose the generators and feeders are connected to conducting bars, or 'bus bars.

The simplest arrangement of 'bus bars is that shown in fig. 1.

In most systems some arrangement of duplicate 'bus bars is provided. Some engineers contend that this duplication of 'bus bars is unnecessary,

and the construction and appearance of a switchboard are undoubtedly simplified by the use of one set of bars.

Simplicity in working should not, however, be sacrified in order to attain simplicity in construction, and the author has found from conversation with other engineers, and from personal experience, that in actual practice cases are constantly arising where the provision of duplicate bars, or some means of dividing the system into sections, has proved most valuable.

In making arrangements for duplicating 'bus bars the following points should be considered:—

(*a*) It should be possible to isolate any section of the switchgear controlling a feeder or generator without interfering with the continuity of the supply.

(*b*) It should be possible to run any feeder which may be considered weak and liable to break down on a generator not connected in parallel with the remaining working generators.

(*c*) In the event of a serious break-down necessitating a complete shut-down, it should be possible to start up different machines on different independent sections of feeders.

(*d*) It may be convenient when running on full load to connect the long feeders supplying outside districts to a section of the 'bus bars maintained at a somewhat higher potential than the 'bus bars to which short feeders are connected.

(*e*) Where very heavy currents have to be dealt with, the feeders should be connected alternately with the generators at points along the whole length of the 'bus bars, for to connect all the feeding points at one end and all the generators at the other would necessitate the sectional area of the 'bus bars being sufficiently heavy to carry the whole of the current.

(*f*) It is in some cases desirable that main ammeters and wattmeters should be connected in some portion of the 'bus bars to record the aggregate output of the generating station.

'Bus bars may be duplicated either by arranging them in the form of a ring or merely by dividing them into sections.

An example of the former method is the arrangement of 'bus bars at the Niagara Falls Power Co.'s stations, shown in fig. 117.

This, it will be seen, is practically a double ring. Each ring is divided into sections, having five or six generators and a number of feeders connected to each section. Each generator and feeder is equipped with a two-way selector switch, by means of which the generator or feeder may be connected to either the inner or outer ring. In this case the two sides of the ring are located in different generating stations, the one side being in the original generating station and the other side in the station that has recently been completed. The ring is completed by interconnecting cables

between the respective stations. It will be seen that this system meets all the requirements specified above, with the exception of provision (*f*). The whole system may obviously, if desired, be run from one generator. On the other hand, the system may be divided into eight distinct sections, each section having its group of generators and feeders.

The Bertram system, illustrated in fig. 118, is another example of 'bus bars arranged on the ring system. In this case all the feeders are connected to one side of the ring, and all the generators to the opposite

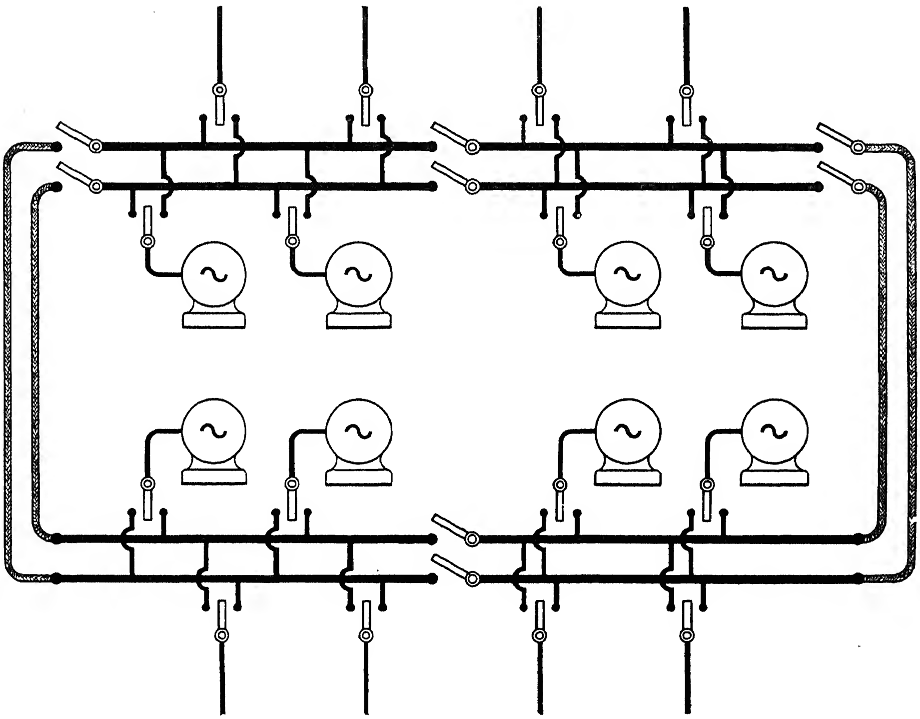


FIG. 117.—Niagara duplication of 'bus bars.

side; each generator section may, however, be connected to the feeder section directly opposite to it. Isolating switches A, consisting of simple knife switches, are inserted between each section of the 'bus bar. The switch B is usually left open, in order that the whole of the current may be recorded by the measuring instruments C. It will be seen that this arrangement fulfils requirements (*a*), (*b*), (*c*), (*d*), and (*f*), but does not provide for (*e*). This, however, is not important for high-tension systems.

Mr Clothier, in his paper on "Central Station Switchgear" previously referred to, gives diagrams of various arrangements of 'bus bars, and also

suggests one or two methods of duplicating or dividing them into sections. One of the arrangements suggested is shown in fig. 119.

This arrangement meets requirement (*a*) as far as the generators are

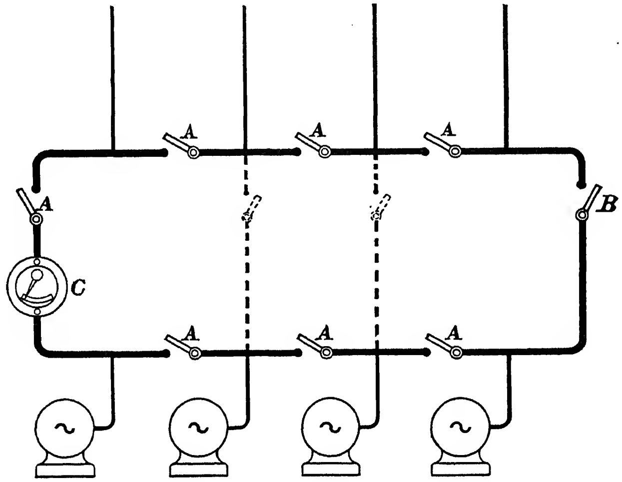



FIG. 118.—Bertram's system of ring 'bus bars.

concerned only. Requirement (*b*) cannot be dealt with. Requirement (*c*) is met to a limited extent only, though probably sufficiently so for small installations. Requirements (*d*) and (*e*) are satisfactorily fulfilled, but (*f*) cannot be dealt with.

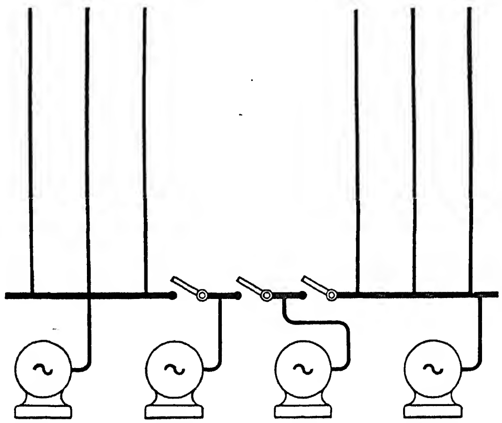


FIG. 119.—Clothier's system of duplicate 'bus bars.

The arrangement of the 'bus bars in the generating station of the Metropolitan Street Railway Company in New York is shown in fig. 120. The generators A are in the first place connected by short 'bus bars into

four distinct groups. Each of these groups may be connected to two sections of the feeder 'bus bars, through selector switches $F_1$ $F_2$. To the feeder 'bus bars $G_1$ $G_2$ groups of four feeders are connected through group switches H. Each group of feeders feeds two stations, and each sub-station is connected to two distinct groups on different, though adjacent, sections of the feeder 'bus bars. This arrangement, though apparently at first sight unnecessarily complicated, is probably justifiable for such a large and important scheme as that referred to. It will be seen that there is not a point on the whole conducting system that cannot be completely isolated without interruption of the supply to any other distributing centre. All the requirements specified are fully dealt with, with the exception of (*f*),

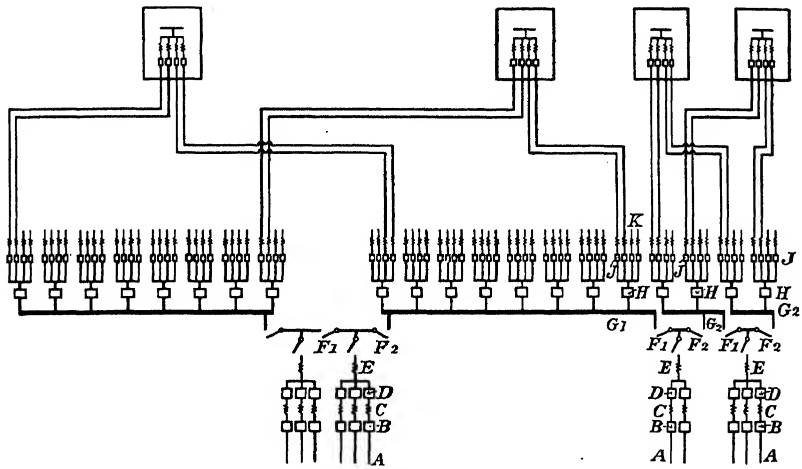



FIG. 120.—New York Metropolitan system of duplicate 'bus bars. The lettering of this diagram corresponds to that of Fig. 145.

and this is met to a certain extent by measuring instruments between the groups of generators and the groups of feeders.

Fig. 121 illustrates a simple method of duplicating 'bus bars, designed by the author, that has been in use at Hastings for some years. The spare 'bus bar is divided into two sections, one for the generators and one for the feeders. Under normal conditions all the working generators are connected directly to the upper 'bus bar A. The feeders are also connected to this upper 'bus bar, but some of them indirectly through the feeder section of the spare 'bus bar and through the two-way water break switch C. The feeders are arranged so that the load on the spare feeder bar is approximately equivalent to the output of the spare generator. One generator is connected to the spare machine 'bus bar $B^1$. Should one of the working generators fail, the faulty generator is switched out of circuit, and at the same time the two-way 'bus bar switch C is thrown over, thereby discon-

necting from the working 'bus bar a load approximately equivalent to the output of the faulty machine, and this load is then carried by the spare machine. The main ammeter and wattmeter are connected in series with the outer 'bus bar. No circuit-breakers are used on the feeders beyond the ordinary fuses. If it is required to switch a feeder out of circuit, this feeder alone is connected to the spare 'bus bar, and the circuit is broken by the water break switch C. This arrangement of 'bus bars fulfils requirements (*a*), (*b*), (*c*), (*d*), and (*f*), but does not provide for (*e*).

Before generators, or sections of 'bus bars, are connected in parallel it

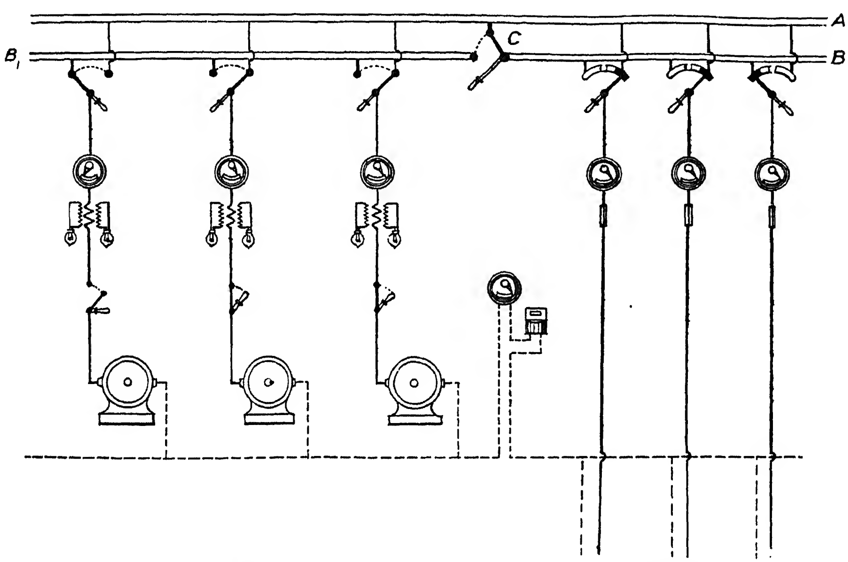



FIG. 121.—Method of duplicating 'bus bars employed at Hastings.

is necessary to take steps to ascertain that there is no difference of potential across the paralleling switch before it is closed.

For continuous current systems the only instruments that are necessary for this purpose are two voltmeters to be connected across the two terminals of the respective generators to be connected in parallel, or one voltmeter to connect across the paralleling switch. In the former case the two instruments must read alike, and in the latter case the voltmeter should indicate zero potential before the paralleling switch is closed.

For alternating current systems, in addition to the above, it is necessary to ascertain :—

(1) That the incoming generator is running at exactly the same speed as the working generator.

(2) That the phases of the incoming and running machines exactly coincide.

For this purpose it is necessary to employ a device known as a synchroniser.

The simplest device of this description consists of two lamps connected in series across the two end coils of the generators to be paralleled. When both generators are in phase and developing equal E.M.F. there will be no difference of potential across the lamps, and as a consequence the lamps will not glow. When, on the other hand, the generators are 180 degrees out of phase there will be a difference of potential across the lamps equivalent to the sum of the E.M.F. of the two coils, and if the voltage of the lamps has been selected to suit these conditions, they will glow with full brilliancy. With this arrangement it is obvious that the proper time to parallel is when the lamps are out. The practice of paralleling with blackened lamps is universal in the United States; in this country, on the other hand, it is usual to parallel when the lamps are at full brilliancy. The advantage of the latter arrangement is that it is much easier to detect small differences of potential at full voltage than at zero; that is to say, the difference between 95 and 100 volts on a 100-volt lamp can be easily detected, but the difference between zero and 20 or 30 volts is often not apparent.

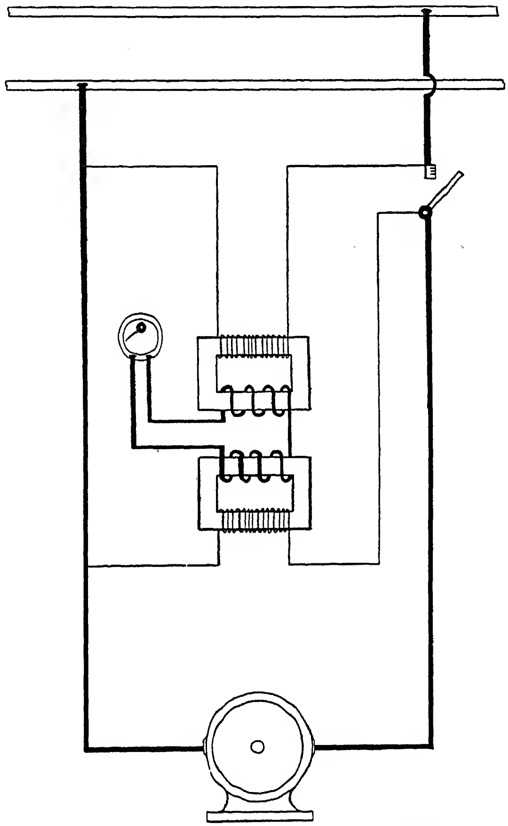


FIG. 122.—Ordinary connections to synchroniser transformers and voltmeter.

The usual apparatus for synchronising consists of a pair of transformers; the primary winding of one of these transformers being arranged to be connected across the working 'bus bars, and that of the second transformer to be switched on to the incoming generator. A lamp or a voltmeter is connected across the secondaries of the two transformers coupled in series,

as shown in fig. 122. When the generators are in phase the two secondary windings assist each other, and consequently the lamp glows at full brilliancy, and the voltmeter indicates the maximum reading. When the generators are out of phase the two secondary windings oppose each other, and there is no difference of potential across the voltmeter and lamp.

The synchronising transformers are sometimes mounted in a small case, upon which the voltmeter and lamps are fixed, and this complete apparatus is provided with four feet, to which the respective primary windings of the two transformers are connected, the feet thereby constituting the necessary primary terminals of the synchroniser. These terminals rest on insulated contacts connected to the switches by means of which the synchroniser is connected to the 'bus bars and incoming generator. By this arrangement it is a simple matter to replace a faulty instrument by another, as it merely entails lifting the one down and putting the other in its place.

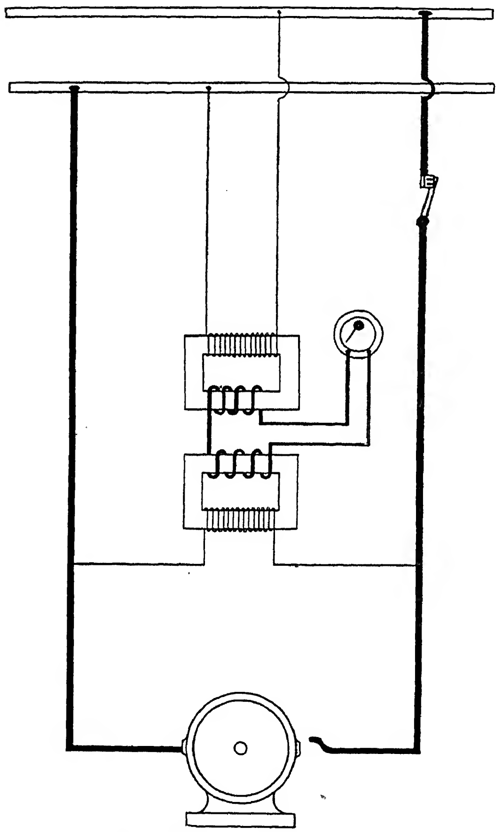


FIG. 123.—Method of testing synchroniser connections.

It is usually only considered necessary to provide one synchroniser for a number of generators. For this purpose it is necessary to connect one of the transformers to a synchroniser 'bus bar, through which it may be plugged on to any generator. It is desirable that only one plug should be used for this purpose, as it will be evident that if two generators are plugged on to the synchroniser 'bus bar they may be connected in parallel through this 'bus bar when they are out of step, and serious consequences may result.

In Messrs Ferranti's standard high-tension switchboards, instead of a

synchronising plug, arrangements are made for connecting the incoming generator to the synchronising 'bus bars by placing the generator switch at half-cock. It is, of course, necessary in this case to take every care to see that two switches are not placed at half-cock simultaneously, as the result would obviously be the same as using two plugs in the manner referred to above.

In some cases a separate synchroniser is used for each main switch, which arrangement, though slightly more costly to instal, has many advantages.

When connecting up a synchroniser for the first time, it is sometimes difficult to ascertain which way the synchronising transformers are wound. It is obvious that, should a mistake be made in making these connections, the synchroniser lamp will glow when the generators are out of phase, and will be extinguished when they are in phase, and as a result of this incorrect indication generators may be switched into parallel when they are exactly out of phase.

A simple method of testing synchroniser connections is illustrated in fig. 123. The synchronising transformers should be connected up to the 'bus bars and to one of the generators. The leads between the generator and the switchboard should then be removed from the machine, and the paralleling switch closed. It is obvious that when this switch is closed the generator leads, across which one side of the transformers is connected, must be in phase with the 'bus bars. If, therefore, the synchroniser transformers have been properly connected up, the lamps and voltmeter will indicate the maximum potential across the secondary terminals. Should they not do so, the connections to one of the transformers should be reversed and the test repeated.

Although it can be seen when running a machine up before connecting it into parallel whether or not it is in phase, the ordinary synchronising lamp and voltmeter do not show whether the incoming generator is running too fast or too slow; and consequently time is often lost through increasing the speed of a machine when it is already going too fast, or *vice versa*. To overcome this difficulty various methods have been suggested for showing whether the incoming generator is running too fast or too slow.

Mr Ferranti, some years ago, drew attention to the fact that if a generating station is lighted by alternating current arc lamps supplied by the working generators, the pole pieces of the incoming generator appear to stand perfectly still when the incoming machine is running at the same speed as the working generators, whereas if the incoming machine is running faster than the other machines the pole pieces appear to slowly revolve in the direction in which the generator is being driven. If, on the other hand, the incoming machine is running at a slower speed than the working generators, the pole pieces appear to revolve against the normal

direction of rotation. This phenomenon is, of course, due to the fact that the light from an alternating current arc lamp is intermittent, the fluctuations corresponding to the periodicity of the supply. The light will be a maximum when the pole pieces are in a certain position relatively to the armature coils, and consequently the pole pieces of the machines supplying the current have the appearance of always standing in this position. If the incoming machine is running at the same speed, it will also have this appearance of standing still. If, however, it is running slightly faster, it will gain slightly on the working machines, and at each period of maximum illumination the pole pieces will be slightly in advance of the position they held the period before. This gives the appearance of a slow rotation in the direction in which the generator is being driven. If, on the other hand, the incoming machine is running slightly slower than the others, it will, of course, have the reverse effect.

A rotary synchroniser has recently been invented independently by Messrs Everett and Edgcumbe in this country and by Mr Paul Lincoln in the United States. This device is practically a small alternating current motor, the armature of which rotates in a clockwise direction if the incoming generator is running too fast, and in a contra-clockwise direction if the generator is running too slow. It consists of a laminated core running in ball bearings and carrying a pointer. The core or rotor is wound with an ordinary two-phase winding, connected to three slip rings. Outside the rotor is a laminated stator, which is also provided with a four-pole two-phase winding. In the case of both rotor and stator one circuit is connected across the full voltage with a lamp in series with it, while in the other is inserted a choking coil; thus two rotary fields are produced, and the connections are such that they rotate in the same direction; obviously they will tend to rotate 'in step.' Now the stator is connected to the 'bus bars, and the rotor to the incoming machine. Supposing both these to be giving the same frequency, the two fields will be rotating at the same speed, and consequently the rotor will stand still; if, on the other hand, the frequency (*i.e.* the speed of rotation) of the stator current is greater than that of the rotor, the latter will have to revolve in the same direction as the flux in order that the two fields may keep in step. Thus, for example, a clockwise rotation will show that the frequency of the incoming machine is too great, while a contra-clockwise rotation will show that it is too small. The speed of rotation is also an indication of the difference between the two frequencies, one complete revolution representing, in fact, a difference of two cycles.

A feature possessed by the Everett and Edgcumbe synchroniser only is the arrangement of two lamps, coloured respectively red and green, which are automatically exposed to view according to the direction of rotation of the spindle; the result is that the engine-driver can see at a considerable

distance whether his machine is going too fast or too slow. The whole apparatus is surmounted by an ordinary synchronising lamp, not for use by the man switching in, but as a guide to the engine-driver. The red or green lamp indication is effected by means of a small lever which is carried friction-tight on the spindle, and which actuates a two-arm shutter. When the pointer is rotating in one direction the shutter shows a green light, whereas when the rotation is in the opposite direction a red light is shown.

The British Schuckert Co. exhibited at the Paris Exhibition in 1900 and at the Glasgow Exhibition in 1901 a rotary synchroniser consisting of a

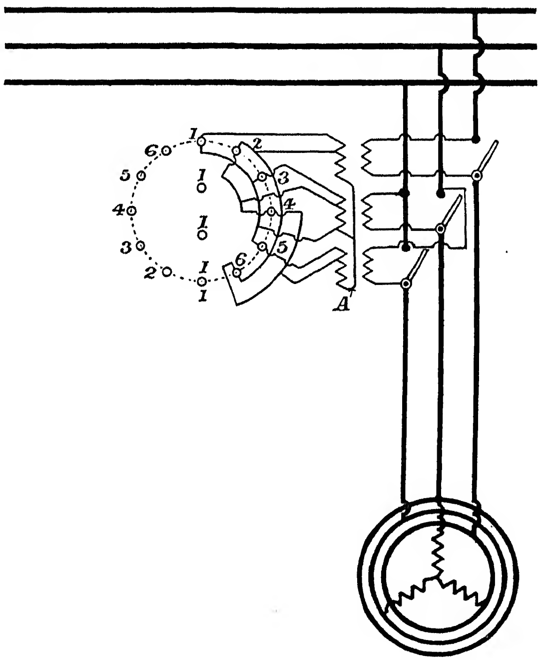



FIG. 124.—British Schuckert rotary synchronisers.

bank of lamps arranged in a circle and connected to the secondary windings of a three-phase transformer. The method of connecting up this three-phase transformer is shown in fig. 124.

For simplicity, the connections to only half the glow-lamps have been shown; in practice lamps diametrically opposite each other are coupled in parallel. By means of the lamp connections each secondary is divided into two parts. The point of connection is so chosen that the number of windings between this point and the common point of connection A of the three coils bears to the total number in the coil the ratio of $\frac{\sin 30°}{\sin 60°} = \frac{1}{\sqrt{3}}$.

The pressure in the primary coils of the transformer is the geometrical

difference of the component parts of the pressure delivered by the 'bus bars and the terminals of the machine. The pressure in the secondary coils is proportional to that in the primary, and is the same if the number of windings in both is the same, which, for simplicity, will be assumed to be the case. Should the working machines and the machine to be connected be already rotating at the same speed—which does not necessarily involve their being in phase—the distribution of pressure over all three coils remains steadily the same, and consequently the lamps connected to the corresponding secondaries will also be under the same steady pressure. The distribution of pressure to the individual lamps is, however, different. Certain lamps receive a maximum pressure, others less, and with some the

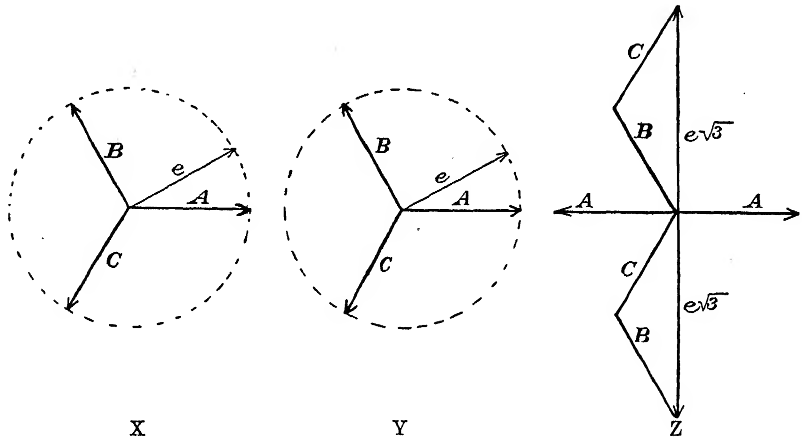



Fig. 125.—Diagrams showing pressure components of synchroniser coils and geometrical differences in the components when generators are in phase.

pressure is nil. The distribution of pressure between the lamps depends on the phase difference between the pressure components of the primaries. If the machines are in phase, the pressure components of the three coils are as shown in diagrams X and Y, and the geometrical differences in the components are as shown in diagram Z, fig. 125. If the pressure between one of the 'bus bars or machine terminals and the neutral point is denoted by $e$, then the pressure in coil I. will be $o$, while that in coils II. and III. amounts to $e\sqrt{3}$.

From this the pressure on the individual lamps will be found to be—

$$\text{Lamp 1} = o$$

$$\text{Lamps 2 and 6} = e\sqrt{3}\,.\frac{\sin 30^\circ}{\sin 60^\circ} = e.$$

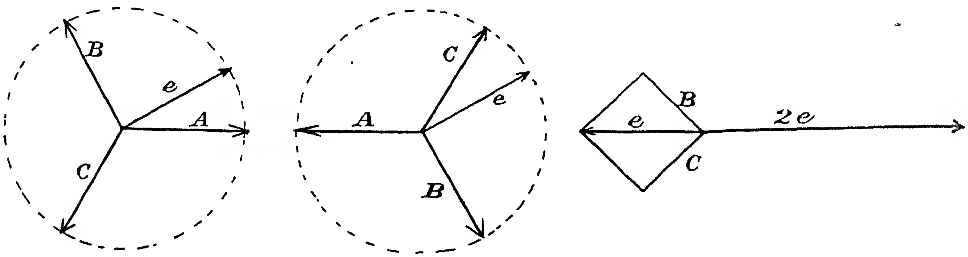
$$\text{Lamps 3 and 5} = e\sqrt{3}.$$

$$\text{Lamp 4} = e + e = 2e.$$

But

$$o = 2e \cdot \sin o^\circ.$$
$$e = 2e \times \tfrac{1}{2} = 2e \cdot \sin 30^\circ.$$
$$e\sqrt{3} = 2e \cdot \tfrac{1}{2}\sqrt{3} = 2e \cdot \sin 60^\circ.$$
$$2e = 2e \cdot \sin 90^\circ.$$

The pressure on each lamp, therefore, is proportional to the sine of its angle from the line 1, 1, 1, 1, and in consequence lamp 4 burns brightest, and lamp 1 not at all. If, on the other hand, there is a phase difference of 180°, then the pressure components are as shown in diagrams $X^1$ and $Y^1$, fig.




$X^1$ $Y^1$ $Z^1$

FIG. 126.—Diagram showing pressure components, etc., when generators are out of phase.

126. The geometrical differences in diagram $Z^1$ show for coil I. $2e$, for coils II. and III. $e$, and the pressure on the various lamps will be—

$$\text{Lamp 1} = 2e.$$
$$\text{Lamps 2 and 6} = \frac{2e}{\sqrt{3}} + \frac{e}{\sqrt{3}} = e\sqrt{3}.$$
$$\text{Lamps 3 and 5} = e.$$
$$\text{Lamp 4} = e - e = o.$$

The lamp pressures stand in the same proportion as before, but the distribution has altered in such a way that the illumination produced has been turned through an angle of 90°.

For phase difference between 0 and 180° the illumination occupies intermediate positions.

Now two alternate current systems, between which no synchronism exists, may be regarded as being out of phase by a continually varying amount, and consequently, as long as the machine to be connected is out of synchronism with those already running, the lamps of the synchroniser will be illuminated in rotation. According as its periodicity is too high or too low, the rotation will be in one direction or the other, and the difference in periodicity may be judged by the rapidity of the rotation.

To use the apparatus for paralleling machines, it is necessary to wait

until the rotating illumination comes to rest, and as soon as it is produced by certain lamps—viz., the phase lamps 1, 1, 1, 1—the generators may be coupled in parallel.

If it is desired to use the apparatus for single-phase machines, this can be done by employing subsidiary phases produced either by windings of different induction or condensers in the usual manner.

A simple single-phase rotary lamp synchroniser, designed by the author, is illustrated in fig. 127.

This, it will be seen, consists of a modification of the current direction indicating transformers illustrated in figs. 104 and 105. The windings

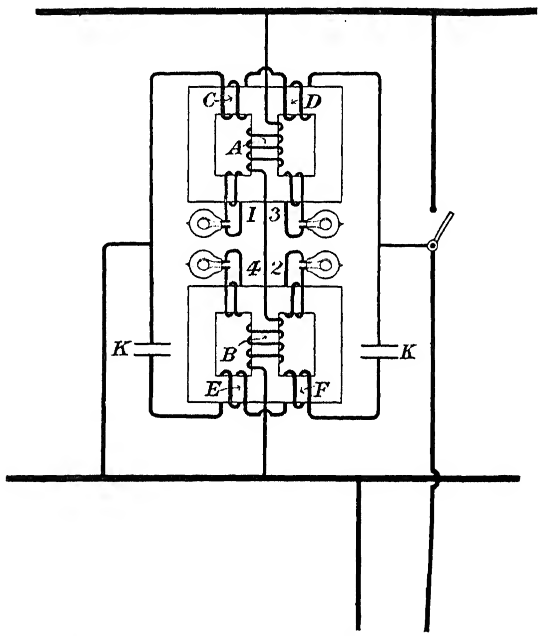



Fig. 127.—A single-phase rotary synchroniser.

A and B are connected across the high-tension 'bus bars. The windings C and D are connected directly across the terminals of the incoming generator, and the windings E and F are shunted across C and D through a condenser K, so that the current in C and D is approximately 90° out of phase with the current in E and F. When the E.M.F. of the incoming generator is in phase with the 'bus bars, lamp 1 will be fully lighted and lamp 3 will be extinguished; whereas lamps 2 and 4 will both be half incandesced only. If a moment later the incoming generator gets 90° in advance of the 'bus bars, lamp 2 will be fully incandesced, lamp 4 will be black, and lamps 1 and 3 will be half incandesced only. When the incoming generator has gained 180° on the working generators, lamp

3 will be fully incandesced, 2 and 4 will be semi-incandesced, and 1 will be black. Thus it will be seen that when the incoming machine is running faster than the working machines the point of maximum brilliancy will rotate round the lamps, arranged in numerical order in a circle, in a clockwise direction. If, on the other hand, the incoming generator is not up to proper speed, the maximum point of illumination will rotate in a contra-clockwise direction. The proper moment for synchronising is when No. 1 lamp is fully incandesced and No. 3 is black. If desired, eight lamps may be arranged in a circle, with diametrically opposite lamps coupled in parallel to the respective secondaries (see fig. 128).

A few years ago considerable difficulty was experienced in switching machines into parallel, and various devices were employed to

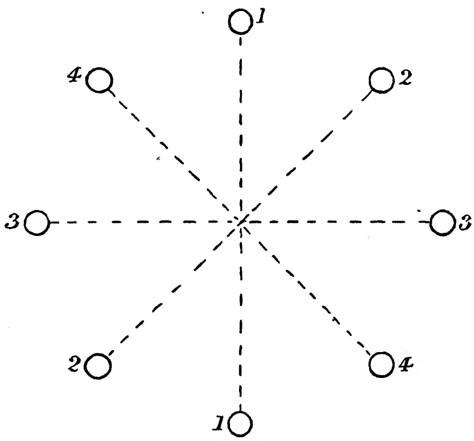



FIG. 128.—Arrangement of lamps for single-phase rotary synchroniser.

prevent the serious consequences of attempting to parallel at the wrong time.

In some cases machines were paralleled through a highly inductive choking coil, the core of which was gradually removed, after the machines had been paralleled through it, and the winding was finally short circuited.

The author designed and used for some years a circuit-breaker so constructed that it was impossible for an attendant to switch generators into parallel if they were badly out of phase. This circuit-breaker is shown opened and closed in figs. 129 and 130.

The main current is carried through the contacts A and B, but this circuit is shunted through the two arms and carbon contacts C. The circuit-breaker is held in the closed position by the toggle-joint D. To close the circuit-breaker the handle E is lowered until the projection F

engages with the catch G on the weighted lever H; the handle and weighted lever are then lifted together into the position shown in fig. 130. In this position the weighted lever is supported by the catch J, and the pin K, pressing on the tail-piece of the catch G, releases the weighted lever from the resetting handle, thus leaving this free to fall if released by the electro-magnet L. This electro-magnet is connected across the secondary of a

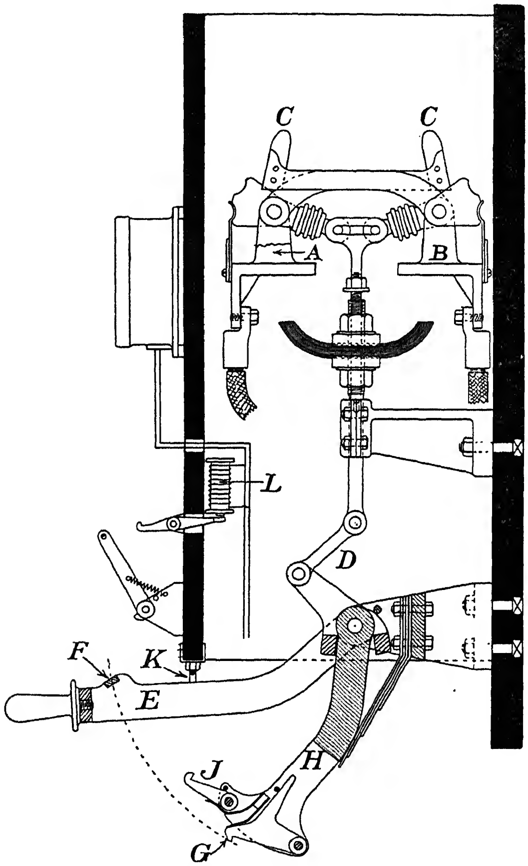



FIG. 129.—500 K.W. carbon-tipped horn break circuit-breaker open.

transformer in series with the main circuit. An excessive current through this will, therefore, release the catch, and the weight in falling will cause the main circuit to be opened, first at A, B, and finally across the carbon points C, and any arc that may be drawn out is effectually repelled by the horn break action of the arms to which the carbon contacts are fixed. The advantage of this arrangement over a fuse is that it can be reset instantly.

It was at one time considered necessary, before connecting a machine into parallel, to run the incoming machine up on an artificial load approxi-

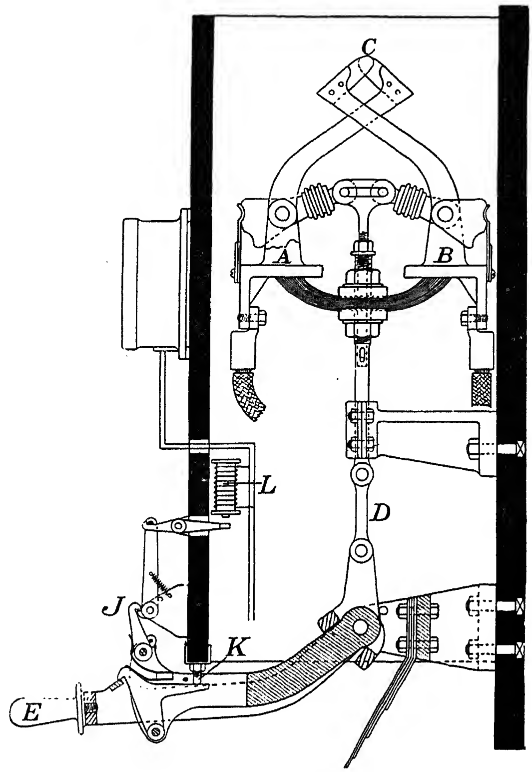



FIG. 130.—500 K.W. horn break circuit-breaker closed.

mately equivalent to the load on the working generators. Practically all modern machines can, however, be paralleled without difficulty.

# CHAPTER VII.

## GENERAL ARRANGEMENT OF CONTROLLING APPARATUS FOR HIGH-TENSION SYSTEMS.

Examples of compact directly controlled switchgear: 'Ferranti' standard high-tension and extra high-tension switchgear, 'Cowan' hinged panel gear, 'Hastings' gear, and 'Brush' standard switchgear—Examples of isolated directly controlled gear: 'Glasgow' cubicle switchgear, 'Raworth' pillar gear—Indirectly controlled systems: 'Berlin' mechanically controlled switchgear, 'New York Metropolitan Street Railway,' and 'Niagara' pneumatically and electrically controlled switchgear.

HAVING now considered, in detail, some of the apparatus required for a complete switchboard, attention may be turned to the general arrangement and assembling of this apparatus.

The various designs that have been adopted are so widely different that it is extremely difficult to classify them. Mr Clothier, in his paper before the Manchester section of the Institution of Electrical Engineers on "High-Tension Switchgear," divides the various constructions into those with spaces behind them, and those without. There are, however, many other distinct divisions; in fact, almost every different design appears to belong to a class of its own.

One very notable difference is in the spacing of the apparatus. Some designers have aimed at getting everything into as small a compass as possible, whereas others have arranged the apparatus controlling each generator, or feeder, in such a manner as to isolate it from its neighbours. Isolated switchgear may be again divided into directly and indirectly controlled gear. In the case of the former the switchboard attendant has to walk from one panel to another, and can as a rule only see the instruments on one panel at a time, whereas in the latter case the actual operating handles and instruments are usually arranged in a very small space, so that the attendant can control everything from one point.

**Compact Directly Controlled Switchgear.**—An excellent example of this class is the well-known Ferranti high-tension switchgear, a section of which is illustrated in fig. 131. The essential features of this design are its simplicity and the entire absence of any earthed metal framework, between which and the high-tension conductors a dangerous arc might

be established. The various switches and instruments are mounted in cells, or compartments, isolated from each other by slate slabs imbedded in the glazed brick wall which forms the background of the switchgear. It will be noticed that there are no cable connections between the various controlling arrangements. The concentric cable from the generator terminates in a cable box A. The outer conductor of the cable is connected to the outer casing of the cable box, and a copper bar bolted directly on to the cable box constitutes the outer 'bus bar of the system. The inner conductor is continued through the cable box to the lower fuse contact B. From this point the current passes through the fuse C, main switch D, and ammeter E, to the main inner 'bus bar F. On a shelf above the main inner 'bus bar the synchronising transformer and voltmeter, the 'bus bar voltmeter, and incoming generator voltmeter are usually mounted. The 'bus bar voltmeter and one side of the synchronising transformer are permanently connected between the 'bus bar and earth, whereas the second voltmeter and the other half of the synchronising transformer are connected to the swinging contact G. Before switching a generator into parallel the main switch is set at half-cock. In this position the moving blade of the switch makes connection with the swinging contact, thus completing the circuit between the incoming generator and earth through the voltmeter and synchroniser. To finally connect the generator to the 'bus bar the switch is pushed home, thus automatically disconnecting it from the swinging contact connected to the synchroniser 'bus bar. Care must be taken to guard against two of the generator switches being set at half-cock simultaneously, as to do this would parallel the two generators through the synchroniser 'bus bar. To prevent a serious accident from this cause, the precaution is sometimes taken of inserting light fuses between this 'bus bar and the swinging contacts.

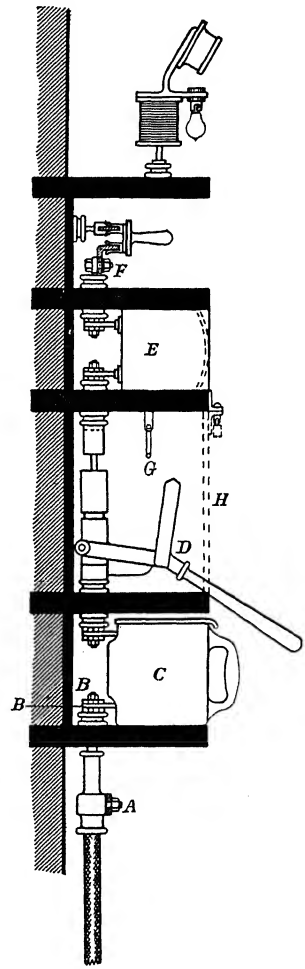


FIG. 131.—Section of Ferranti H.T. switchgear.

The method adopted of locking a switch open, to guard against its

being accidentally closed when men are working upon the generator or feeder, is very neat. A small wooden panel H just fits the front of the switch compartment, and when this is locked into the position shown, it is impossible for the switch to be operated. Fig. 132 is a front view of

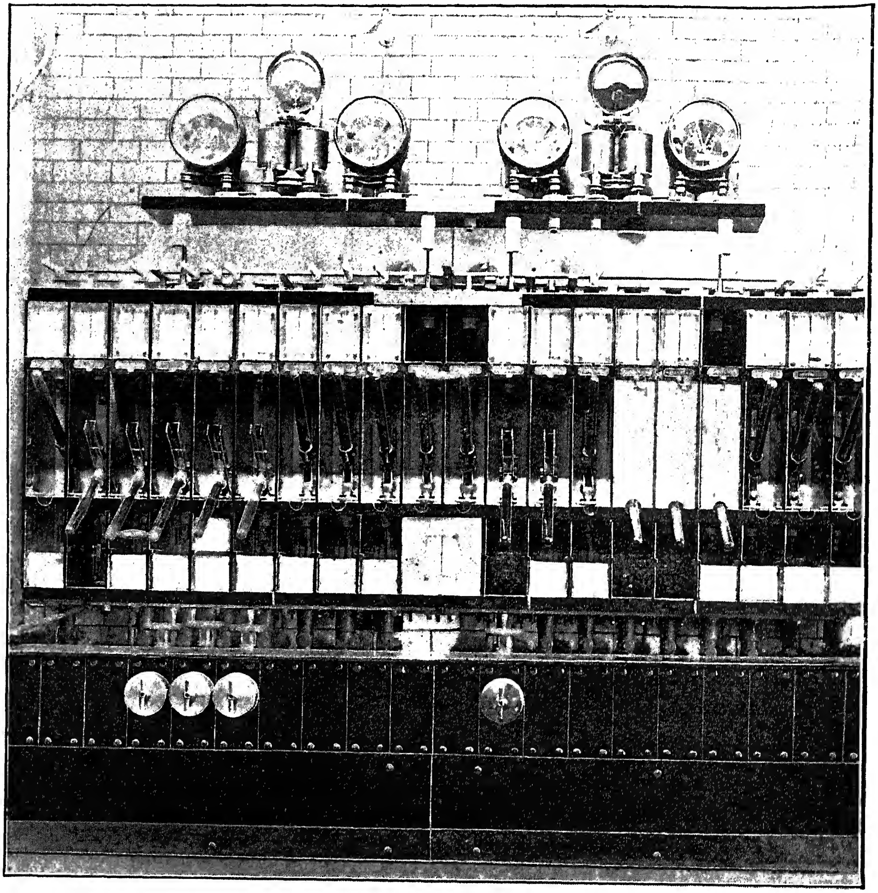


FIG. 132.—Front view of standard Ferranti H.T. switchboard.

a standard single-phase switchboard, each panel of which is capable of controlling 300 kilo-watts at a pressure of 2000 volts.

The field regulating resistances are usually placed below the switchboard gallery and controlled by a handle projecting through the top of the panelled desk in front of the switchboard. The field switches and field voltmeters are also usually mounted on these panels.

A modification of the above is the Ferranti extra high-tension switch-

gear, illustrated in fig. 133. The general arrangement is practically similar to that shown in fig. 131, the chief difference being that it is adapted to receive the extra high-tension multiple break switches and fuses referred to in Chapter III. The illustration shows a 20,000 volt, 100 K.W.

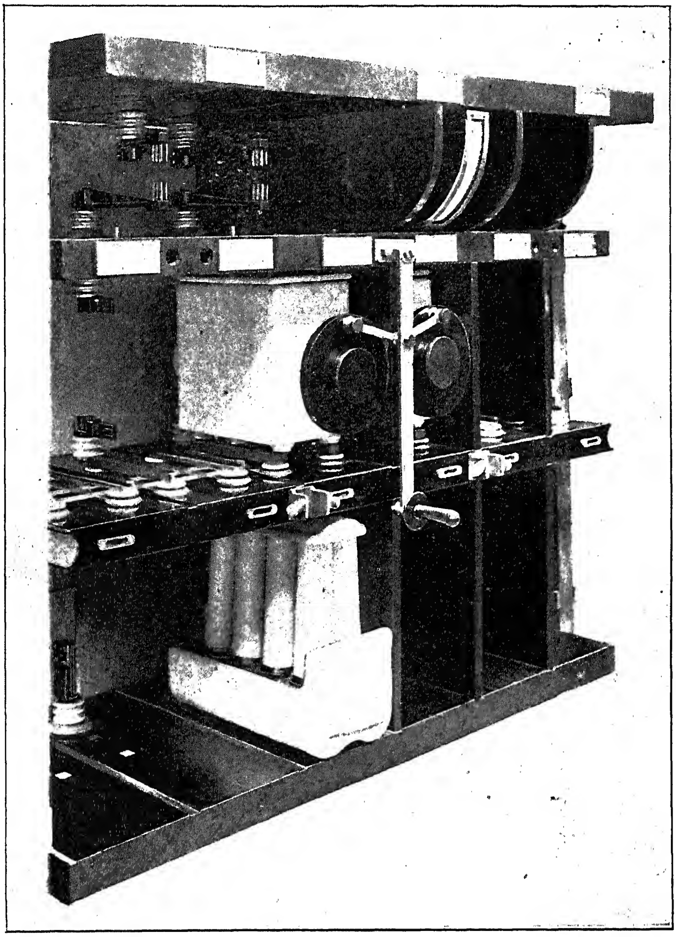


FIG. 133.—Ferranti extra high-tension switchgear.

per panel, two-phase board. The switches on the two phases are linked together so that they may be operated by the movement of one handle.

**Cowan Hinged Wall Type Switchgear.**—Another compact type of switchgear is illustrated in fig. 134. Two further important features of this arrangement are its accessibility for overhauling or extensions, and the very effective precautions that have been taken to guard against an

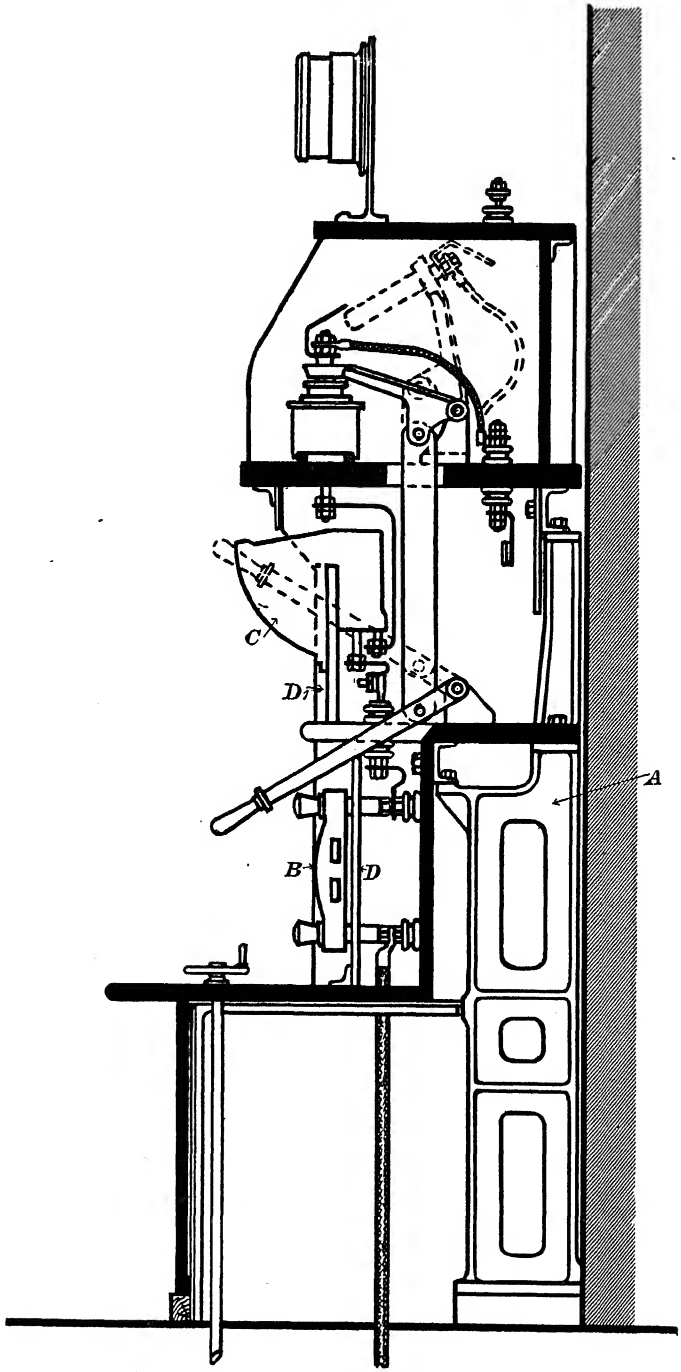



FIG. 134.—Section of Blackpool H.T. switchgear.

attendant making accidental contact with any high-tension connections. The insulating panels are supported on an iron framework A, which may be bolted directly to a wall. By this arrangement the whole of the gear may be assembled in the manufacturer's works, and in consequence the erection in the user's works is greatly simplified. The high-tension fuses B and main ammeters C are mounted on removable panels D, $D^1$, and these panels, when closed, form an efficient guard for the connections behind them. The act of removing these panels disconnects the fuses, etc., from the contacts behind, and affords ready access to these contacts and connections. The circuit in the particular construction shown in fig. 134 is broken by a

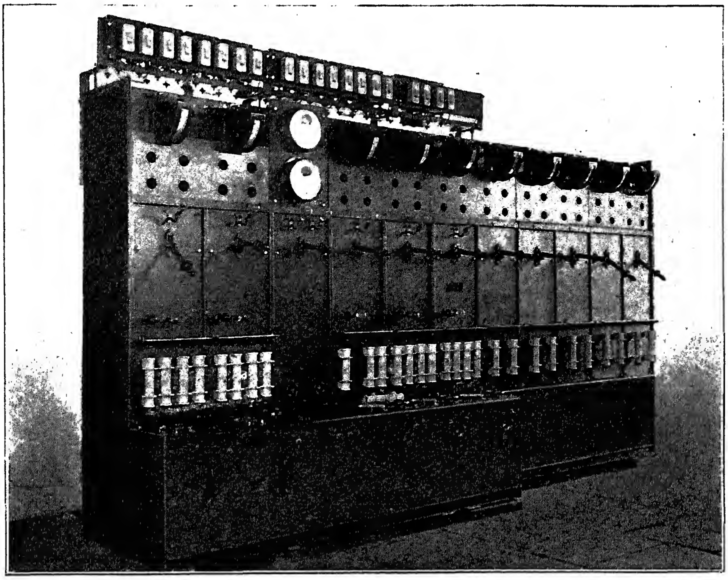


FIG. 135.—Shanghai H.T. switchboard.

water break switch mounted at the top of the board. This switch is controlled by a lever, the handle of which projects from the lower face of the board. In a later design oil break switches are substituted for the water break switches shown.

Figs. 135 and 136 represent a board made for Shanghai by Messrs Cowan, to the specification of Messrs Preece & Cardew.

The apparatus controlling each generator, or feeder, is separated from adjacent sections by slate partitions. It will be seen that, although an iron framework is used for supporting the panels, this is so entirely covered by slate that it is impossible for an arc to be established between it and the high-tension connections.

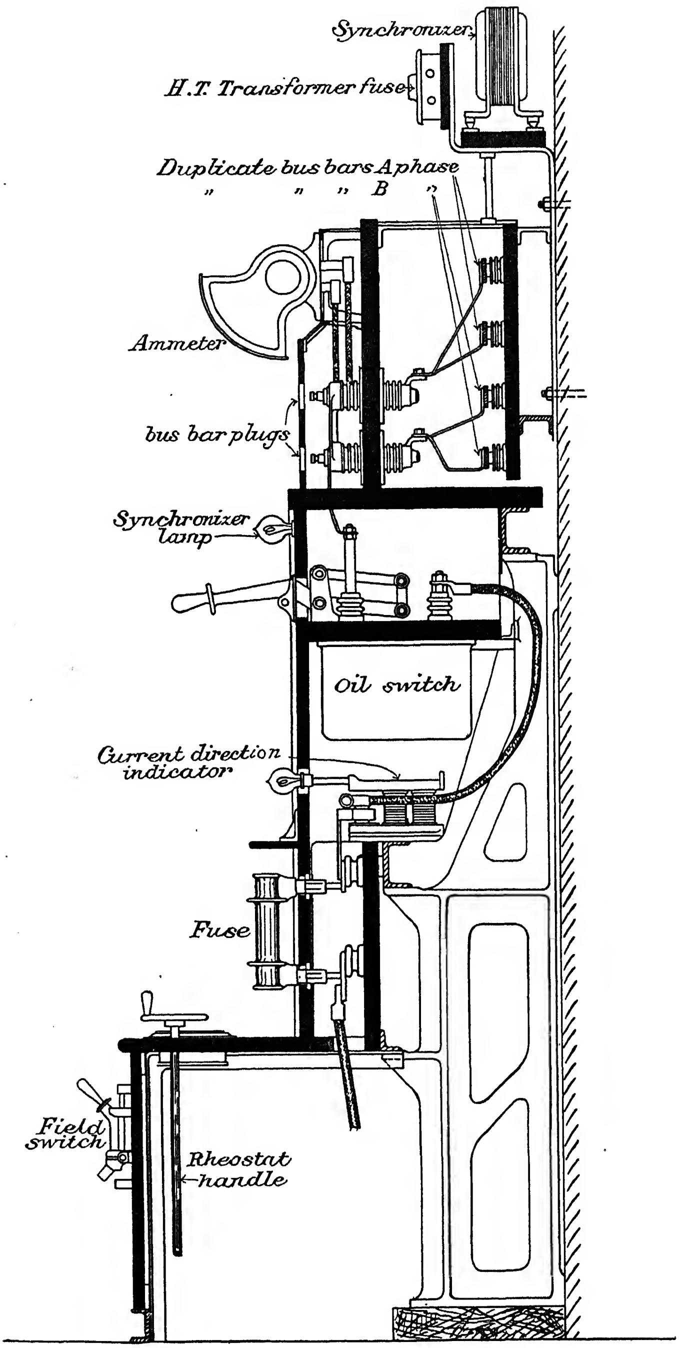



FIG. 136.—Section of Shanghai board.

**Hastings Wall Type Switchgear.**—The switchgear at Hastings (fig. 137) was designed to permit the use of discriminating cutouts for controlling the generators. These cutouts, which also serve as main

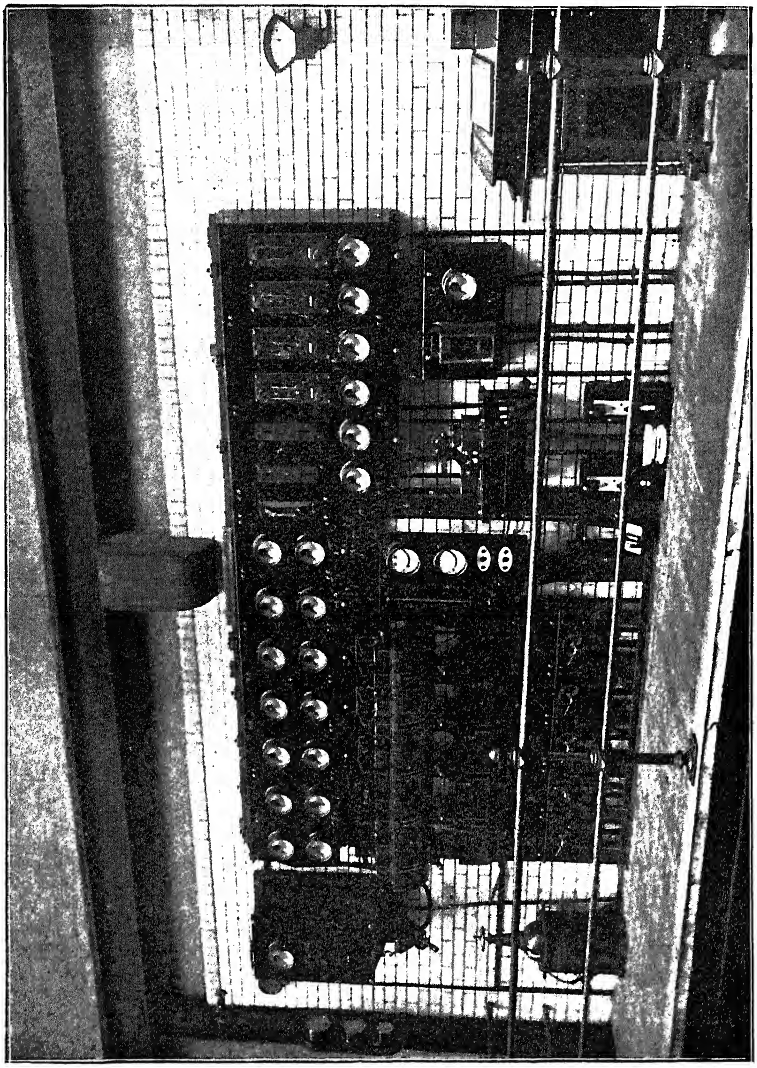


FIG. 137.—Hastings wall type switch-gear.

switches, are bolted to a channel iron framework fixed to a glazed brick wall, which forms the background of the switchboard. The conductors from the generators, etc., are run in iron pipes cleated to the face of the wall in such a manner that the purpose of each conductor can be seen at a glance. A sectional elevation of this arrangement is shown in fig. 138.

The connections are indicated by dotted lines. The conductor on the extreme right is the lead from the inner pole of the generator. This is taken directly into the current-direction-indicating transformer A. From this a wire is run to one of the terminals of the circuit-breaker B; the

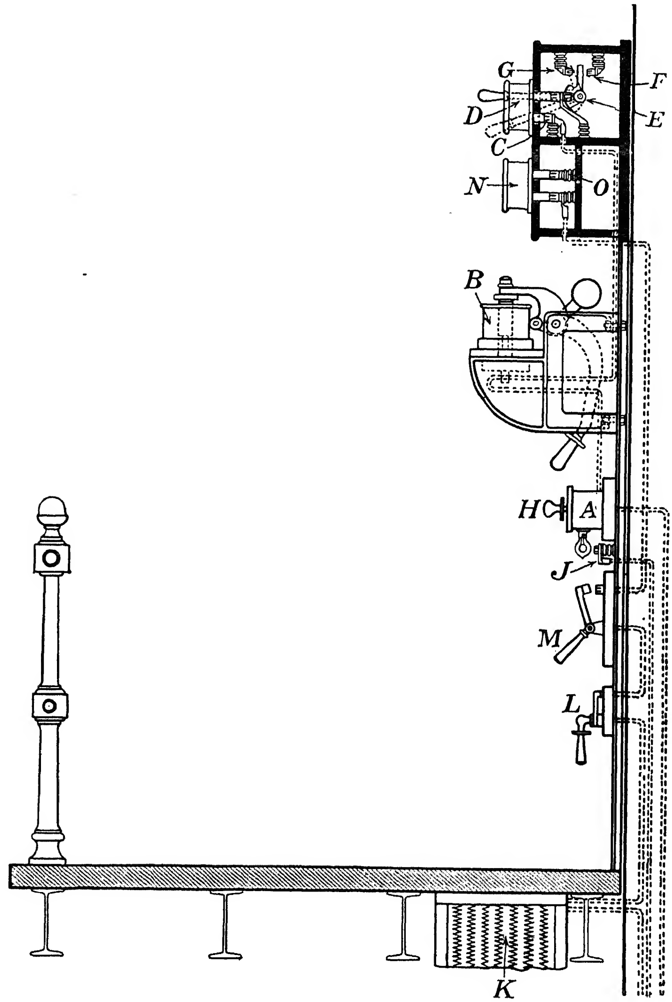



FIG. 138.—Section of Hastings wall type switchgear.

other terminal of this circuit-breaker is connected to the ammeter contact C, the ammeter D, and two-way switch E. By means of this switch the generator may be connected to either of the 'bus bars F or G. Contacts are provided in the transformer A for the synchronising plug H, by means of which the generator may be plugged on to the synchroniser 'bus bar.

The middle conductor shown in the diagram is connected directly between the other pole of the generator and the outer 'bus bar J. The left-hand conductor is taken from one terminal of the field winding through the regulating resistance K, step resistance switch L, field switch M, and field ammeter N, to the field 'bus bar O. The panels on which the main and field ammeters are mounted may be removed for examining the contacts behind them, by loosening four nuts and pulling the panels forward.

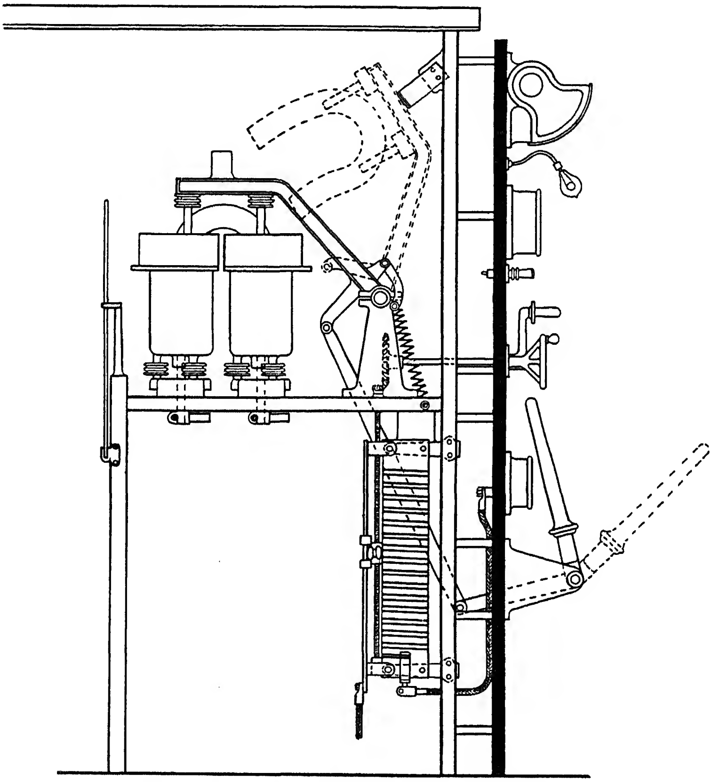


FIG. 139.—Section of Leicester H.T. switchgear.

**Brush Standard High-Tension Switchgear.**—Fig. 139 is a sectional elevation of the switchgear recently supplied by the Brush Electrical Engineering Co. for the Leicester Corporation. In this arrangement the water break switches are mounted on an iron framework at the back of the switch panels, and controlled by an operating handle on the face of the panels. This framework also carries the regulating field resistance, the synchronising transformers, etc. A noticeable feature in connection with this gear is the manner in which the instrument panel is packed off from the supporting framework. By this means the cable connections running at the back

of the panels can be carried on the back of the slate between the panels and the framework. The constant crossing and recrossing of the framework supports is thereby avoided.

**Isolated Directly Controlled Switchgear.**—An example of the Westinghouse cubicle switchgear is to be seen at the power station of the Glasgow Tramways, where it is installed for controlling the high-tension three-phase generators and feeders in use there. Fig. 140 is a diagrammatic plan of the arrangement. The generator circuit-breakers A $A^1$ are mounted on the face of the marble panels F. These generator panels extend across the entire width of the engine-room. All the circuit-breakers used are of the long break Westinghouse type illustrated in fig. 43, Chapter III.

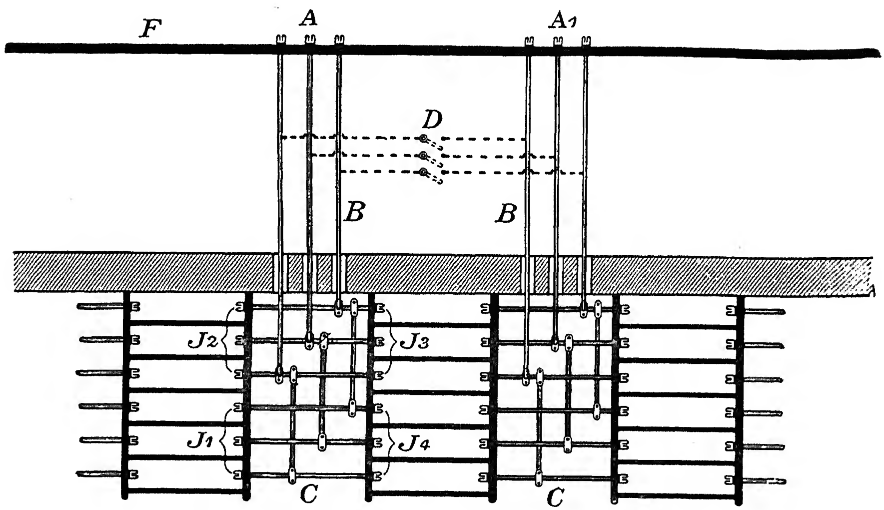



FIG. 140.—Arrangement of 'bus bars and feeder cubicles, Glasgow Tramways H.T. switchgear.

The 'bus bars B, consisting of copper tubes, are supported about 8 feet from the ground behind the generator panels, each generator being connected to an independent section of the 'bus bars. A feeder cubicle C is also connected to each of these sections. The respective sections may, if desired, be interconnected with adjoining sections by the paralleling switches D. These switches are also mounted on the face of the generator panels F. Each of the feeder cubicles contains four main feeder terminal boxes G, fig. 141. The three conductors from each of these terminal boxes are connected through series transformers H H to the bottoms of the three-pole high-tension feeder circuit-breakers $J^1$ $J^2$ $J^3$ $J^4$. These circuit-breakers are constructed to be released by hand, or automatically in the event of an excess current. The operating handles of the switches are mounted on the outer faces of the panels forming the cubicles, together with the ammeters

showing the current taken by each phase of the respective feeders. Fig. 141 shows a sectional elevation of one of these cubicles, and fig. 142 is a view of the space between two adjoining cubicles. Fig. 143 is a view of the connections behind the generator panels F, fig. 140. The only high-tension connections are the tubular 'bus bars to be seen at the upper part of figs. 141 and 143. The heavy 'bus bars running the entire length of the panels in fig. 143 carry low-tension currents only. The various small wires to be

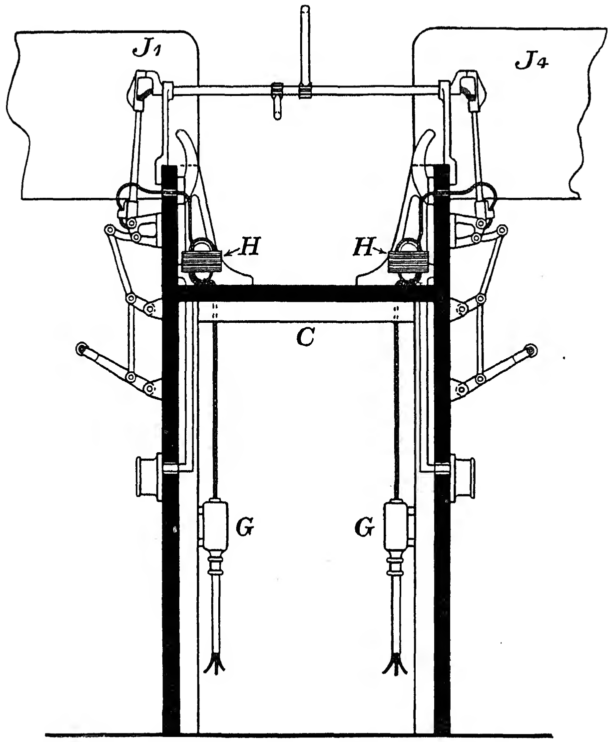



FIG. 141.—Sectional elevation of feeder cubicle (Glasgow).

seen cleated at the back of these panels are connections between the series transformers and the ammeters, wattmeters, etc., on the face of the board.

**Raworth Pillar Switchgear.**—An ingenious arrangement was worked out some years ago by Mr J. S. Raworth. All the necessary switches, measuring instruments, etc., required for controlling a generator were mounted in a pillar, and these pillars were erected directly opposite the generators they controlled. The centre of three operating handles controlled the cross-arm of the double-pole water break switches fixed at the top of the pillar; whereas the handles at the right and left were used respectively for switching on the synchronising transformer and for closing the

field switch. The various handles were so interlocked, the one with the other, that it was impossible for an attendant to operate them in the wrong order.

**Mechanically Controlled Switchgear.**—In order that the actual controlling switches of respective generators may be isolated in such a manner that the effect of a complete burn-out of the controlling arrangements of one generator will be confined to that generator alone, some designers have arranged that portion of the gear at which an arc is liable to be started some distance away from the operating handles, mechanically controlling the one from the other by means of interconnecting rods and levers. An

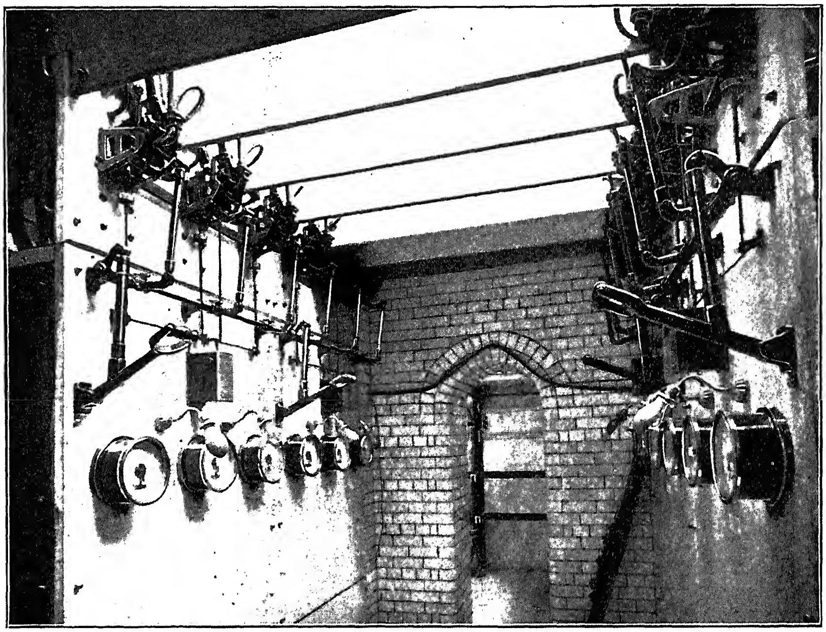


FIG. 142.—Operating panels of feeder cubicles (Glasgow).

example of this arrangement is illustrated in fig. 144. It represents a section of the switchgear constructed by the Allgemeine Co. for one of the generating stations in Berlin. A pair of duplicate three-core cables from each generator terminate in junction boxes A. Fuses B and $B^1$ are inserted in series with the conductors of each phase. These fuses are placed in a cellar below the switchboard floor. The main circuit-breaker C consists of four movable blades on each phase. These blades are mechanically connected together in opposing pairs, the pair of blades on one side being electrically connected together, and those on the opposite side being connected respectively to one of the conductors from the generator, and one of the conductors from the main 'bus bars. The circuit-

breaker controlling each three-phase generator consists, therefore, of twelve movable blades, all of which are controlled by one rod connected to the operating handle J. The movement from this operating handle is transmitted through a rocking shaft D; by this means the necessity of placing the switch directly opposite the controlling handle is avoided, and consequently the spacing between the operating handles is only a fraction of the spacing between the frames carrying the circuit-breakers.

The main 'bus bars are supported on insulators in the cellar below the switchboard floor. The feeder controlling gear is also fixed in this cellar.

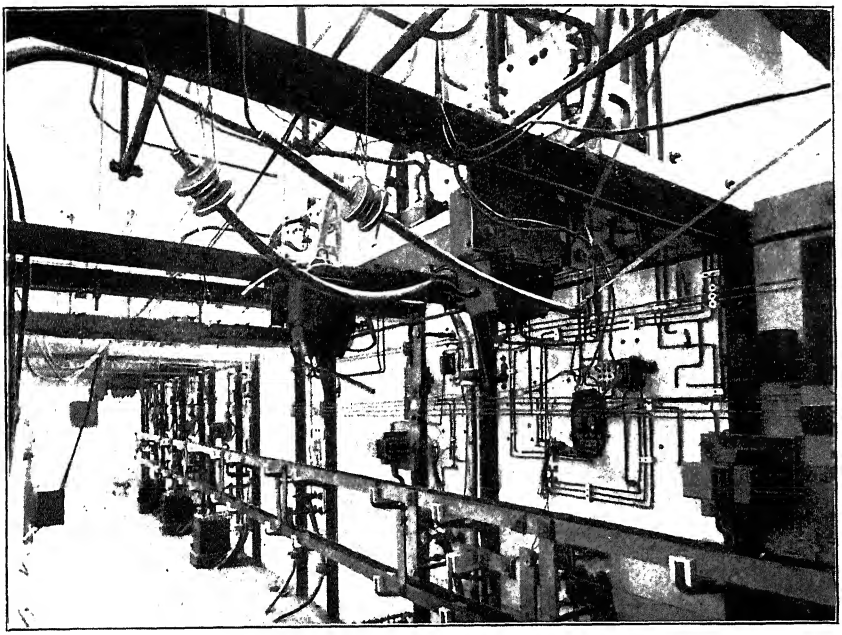


FIG. 143.—Back of generator panels (Glasgow Tramways).

No circuit-breakers, except the feeder fuses, are used for controlling the feeders. The feeder fuses are mounted on a carriage E, which can be run along rails fixed at the top of a rectangular framework. The feeder ammeters F are also supported on this carriage. The feeder circuit is completed through the contacts G and $G^1$ when the fuse carriage is pushed home. To open the circuit the carriage is pulled towards the operator by the handle H; the fuses may thus be examined or replaced without any risk of the operator making accidental contact with the charged connections. No arc is formed upon breaking circuit by withdrawing the fuse carriage, because several feeders are connected in parallel between the generating station and each sub-station.

**American Pneumatically and Electrically Controlled Switchgear.**—The electrical controlling arrangements of some of the large American

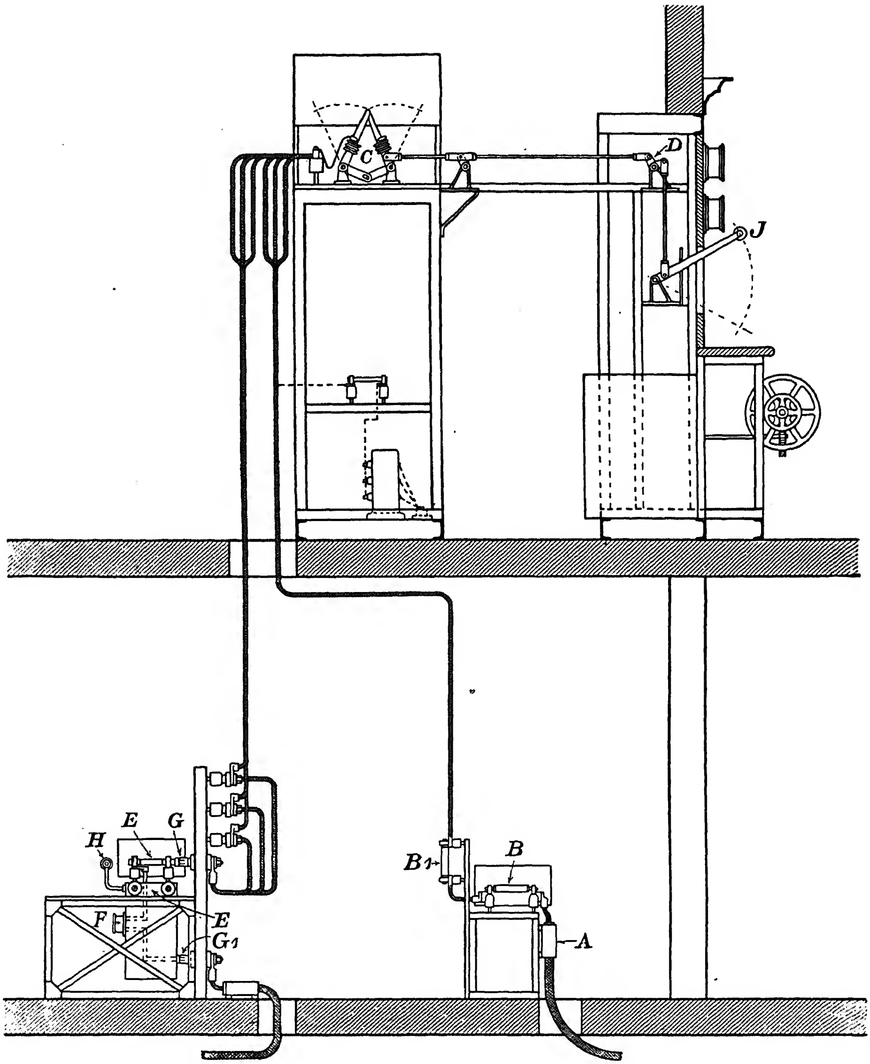



FIG. 144.—Section showing general arrangement of Berlin switchgear.

power plants represent a distinct departure from anything to be found in this country.[1] It almost appears at first sight that the precautions that

[1] Since the above was written three or four boards designed on these lines have been erected in this country.

have been taken are unnecessarily elaborate and costly. When it is remembered, however, that the power to be controlled in one of these generating stations exceeds 40,000 horse-power, and when the very serious consequences of even a momentary interruption to the supply are considered, one realises that the heavy expenditure incurred on switchgear is wholly justifiable.

Fig. 145 is a sectional elevation of the electrical controlling arrangements at the Metropolitan Street Railway Co.'s station in 96th Street, New York. This work has been carried out by the General Electric Co. of Schenectady. All the switching operations are normally conducted at the desk X. A number of miniature switches and 'bus bars on the face of this desk constitute a complete model of the electrical connections and switches in the entire station. These miniature switches are each electrically connected to one of the large circuit-breakers on the floors above. Small red and green lamps inserted at intervals in the miniature 'bus bars, etc., indicate what sections of the connections are dead or alive. The attendant thus has constantly before him a complete diagrammatic indication of the condition of the whole system. The final adjustment of the engines is also controlled from this operating desk by means of a relay acting on the steam governor. When an incoming generator has to be paralleled, the engine-driver starts the plant and runs it up to approximately the speed of the other plants, but the final adjustment is effected by the switchboard attendant. All the measuring instruments required for the system are mounted on panels M behind the controlling desk.

A diagram of the electrical connections of the plant in this station is shown in fig. 120, Chapter VI. The lettering of the various apparatus is the same in figs. 120 and 145. The three-core cable A is connected directly between one of the three-phase generators and the pneumatically controlled circuit-breaker B. The circuit is completed through the ammeter transformer C, a second generator switch D, to the group ammeter transformers and group switches $E^1$, $E^2$, and $E^3$. From this point the current may be directed by selector switches $F^1$, $F^2$, $F^3$ (indicated by dotted lines in fig. 145) to either of the 'bus bars $G^1$ or $G^2$ of each phase. The selector switches are merely heavy multiple-blade knife switches, and are not intended to break the circuit with current on. The construction is, in fact, such that it is impossible to accidentally draw out a heavy arc with these switches. This is effected by a catch which only permits the switch to be opened in the first instance a very short distance. If, therefore, a section carrying current is accidentally opened, a very short arc will result, and the attendant on seeing this can immediately reclose the switch and ascertain the source of the flow of current. From the respective 'bus bars current is conducted to group circuit-breakers H, and through these to the respective feeder circuit-breakers J and feeder ammeter transformers K.

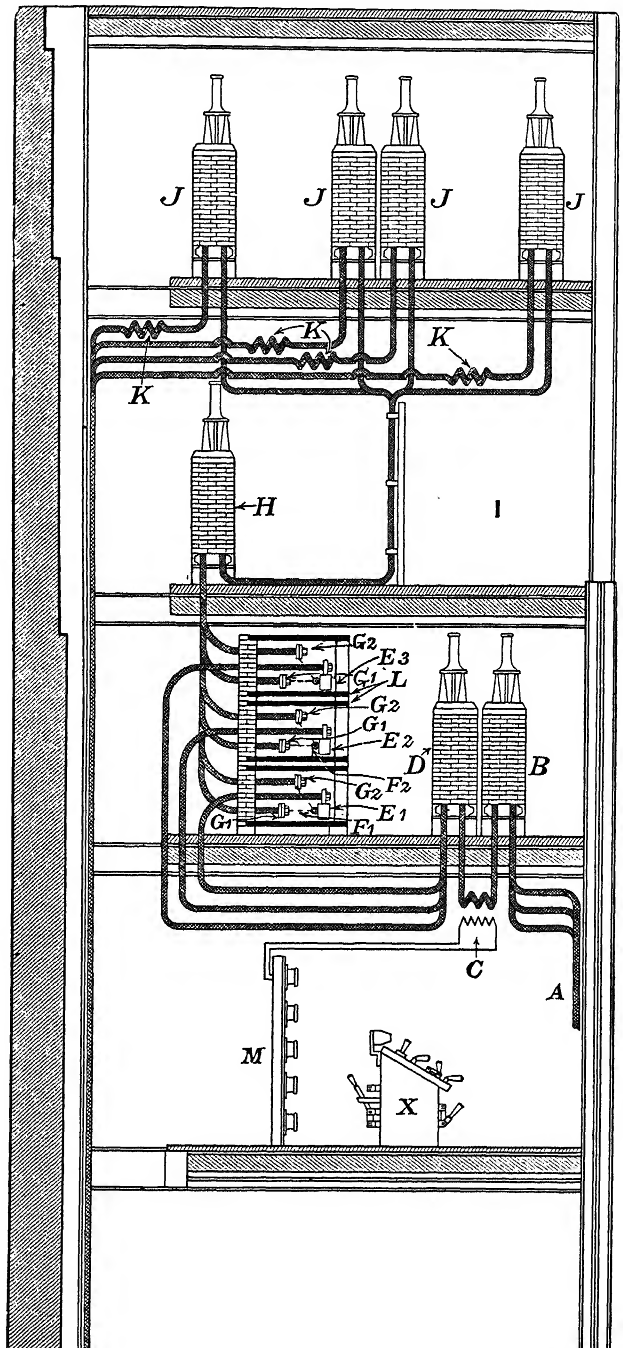



FIG. 145.—Section showing general arrangement of American keyboard switchgear.

The main 'bus bars of the respective phases are efficiently isolated from each other by double soap-stone slabs L.

The construction of the pneumatically controlled oil break circuit-breakers is illustrated in fig. 146. The terminals of each of the circuits to

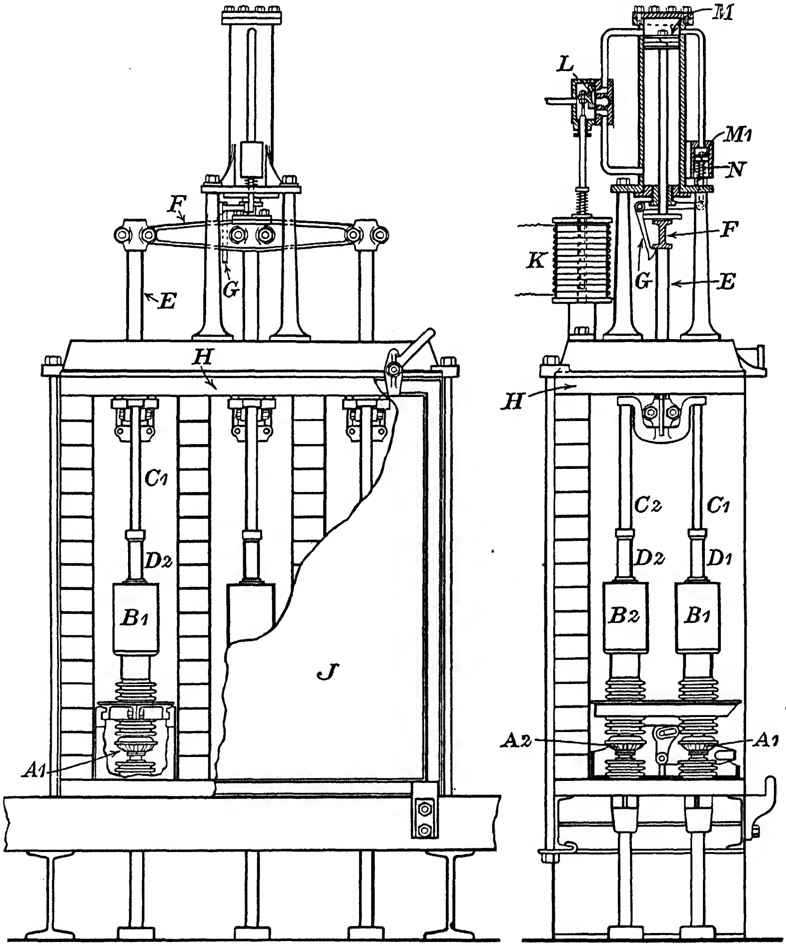



FIG. 146.—Pneumatically operated three-phase circuit-breaker.

be completed are connected respectively to the mushroom-shaped contacts $A^1$ and $A^2$. Metal oil pots $B^1$ and $B^2$ are supported by insulators in such a manner that they rest on, and make connection with, the contacts $A^1$ and $A^2$. Metal rods $C^1$ and $C^2$ connected at their upper extremities are guided through porcelain insulators $D^1$ and $D^2$ into contacts at the bottoms of the oil pots $B^1$ and $B^2$. The circuit is completed through these rods when they are lowered. The movable contacts referred to are carried at the end of

wooden rods E, supported from the cross-beam F. When the circuit-breaker is open, this cross-beam is held up by the catch G. The circuit-breakers inserted in series with the respective phases, though mechanically connected for simultaneous control, are efficiently isolated from each other by brickwork partitions covered at the top by a soap-stone slab H, and in front by an iron door J. It will thus be seen that, in the event of a heavy arc being started across the circuit-breaker controlling one of the phases,

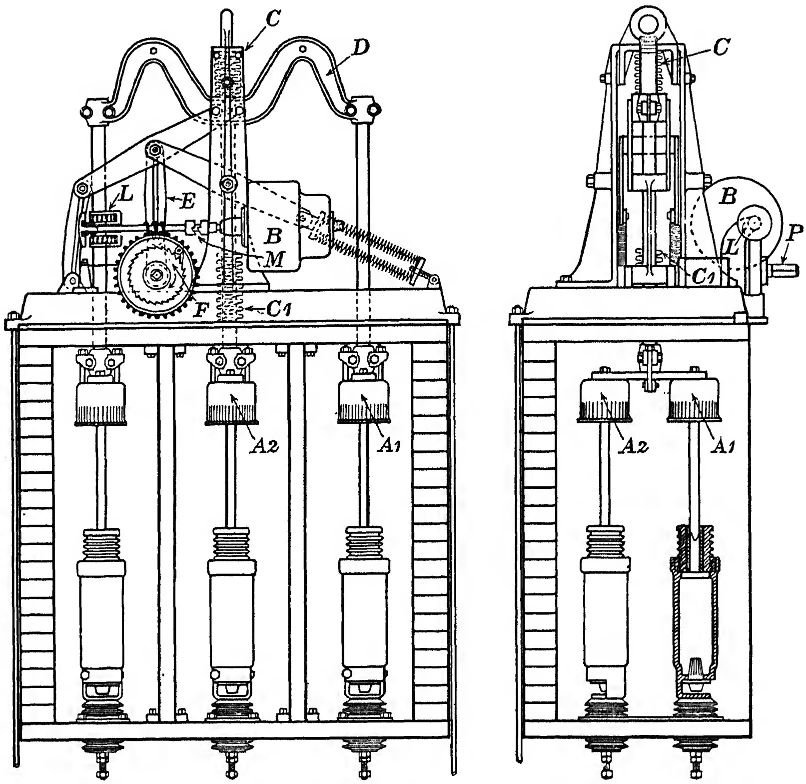



Fig. 147.—Electrically operated three-phase circuit-breaker, open.

it is practically impossible for this arc to make contact with one of the other circuits, and thereby cause a short circuit.

To operate these circuit-breakers a current from a local secondary battery is caused to flow through the solenoid K by closing one of the controlling switches on the operating desk. This draws down the plunger and valve L, and admits air from an air compressor into the cylinder above the piston M. At the same time air is admitted above the small piston $M^1$, and this is forced down against the spring N, thereby releasing the catch G, and allowing the air on the top of the piston M to close the circuit-breaker.

To open the circuit-breaker the movement of the slide-valve L is reversed, thus admitting air below the piston M.

None of the circuit-breakers will be accidentally operated by a failure of the air pressure. The circuit-breakers already closed can only be opened by admitting air pressure below the piston M, and those that are opened can only be closed by admitting air pressure above the piston $M^1$.

A recent modification of the circuit-breakers referred to above is illus-

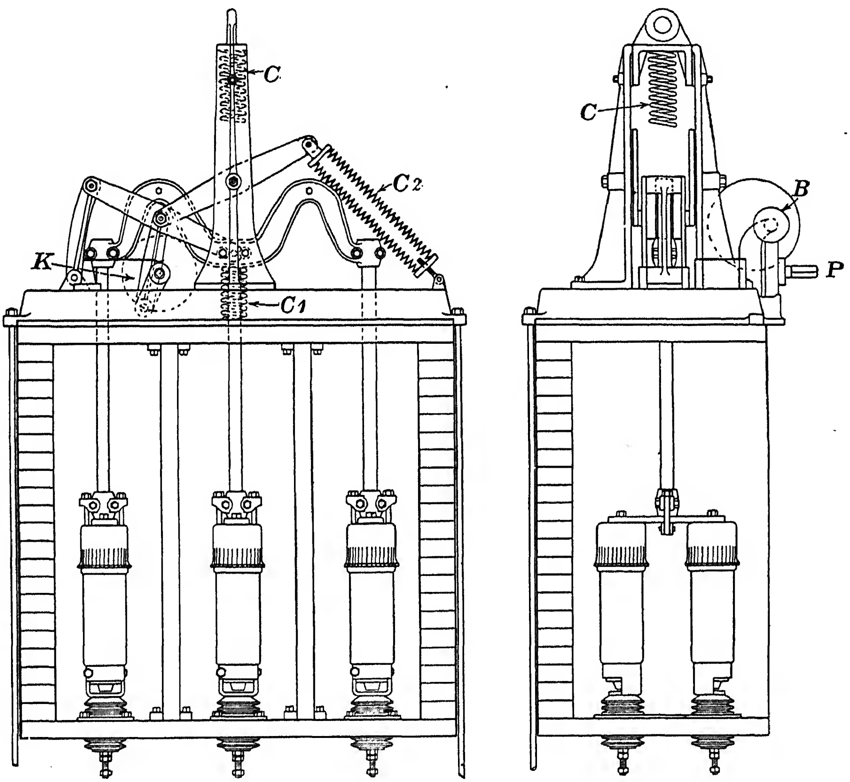



FIG. 148.—Electrically operated three-phase circuit-breaker, closed.

trated in figs. 147 and 148. Fig. 147 is a front and sectional view of one of these circuit-breakers opened, and fig. 148 shows the same circuit-breaker closed. The construction of the oil pots is somewhat similar to that shown in fig. 146, the main difference being that, in addition to the circuit being completed through the rods and contacts in these oil pots, external contacts $A^1$ and $A^2$ are provided to make connection with the oil-containing pots. When the switch is closed the main current is carried by these external contacts, but the circuit is finally broken by the contacts under oil as before.

This circuit-breaker is operated electrically only, without the aid of pneumatics. This is effected by the small series wound electric motor B. A diagram of the connections to this motor is shown in fig. 149, the lettering of this diagram corresponding to that in figs. 147 and 148. When the circuit-breaker is open, a powerful spring C is compressed; this spring tends to force down the cross-arm D. This movement is prevented, however, by the toggle-jointed lever E, the three fulcrums of which are in line with each other. When the circuit is completed through the motor B, this commences to rotate, and turns the wheel F in the direction indicated by the arrow. As, however, one end of the toggle-jointed lever E is connected to the shaft driven by the wheel F, the centre joint of this lever is moved out of the straight line between the fulcrums at each end of the double lever, and consequently this joint is unable to resist the tension of the spring C. This, therefore, causes the cross-arm D to descend, and the lower end of the lever E rotates with the ratchet wheel in a clockwise direction. This rotation will, to start with, be considerably faster than the movement of the driving wheel to which the pawl is attached. As, however, the speed of the motor accelerates, which it will do rapidly, having no work to do, the driving wheel will gain on the ratchet wheel, and will finally drive this through the ratchet and pawl, thus completely closing the circuit-breaker, and compressing the lower spring $C^1$ in doing so. The motor is thrown out of gear when the centre joint of the toggle-jointed lever E has been rotated through an angle of 180 degrees round the shaft. This is effected by means of the commutator G in fig. 149. This commutator is carried and rotated by the same shaft as the ratchet wheel F, the movement being also in a clockwise direction.

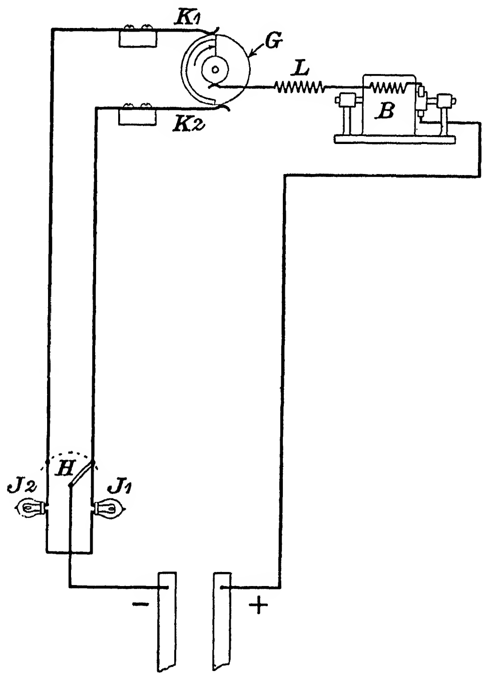


FIG. 149.—Diagram of connections for controlling electrically operated circuit-breakers.

H is a two-way switch on the operating desk, and $J^1$ and $J^2$ are the respective red and green indicating lamps which show whether the circuit-

breaker is opened or closed. The diagram indicates the position in which the switch and commutator are left after the operation of closing the circuit-breaker. The lower brush $K^2$ has just broken circuit with the segment of the commutator connected to the motor and electro-magnet L controlling the clutch M on the motor shaft, and the upper brush $K^1$ has just made contact with this segment. With the switch H in the position shown, no current will pass through the motor except that through the indicating lamp $J^2$, which is incandesced, and indicates that the switch is closed. No current will pass through the lamp $J^1$, as this is short-circuited by the switch H and open-circuited at the commutator brush $K^2$. The small current through the lamp $J^2$ will be insufficient to start the motor B. To open the circuit-breaker the switch H is thrown over to short-circuit the lamp $J^2$. This allows a sufficiently heavy current to pass through the commutator brush $K^1$, the electro-magnet L, and motor B, to throw the clutch in circuit and start the motor. The first movement of the motor carries the centre of the toggle-jointed lever into the position shown in fig. 148, and thus allows the powerful spring $C^1$ to lift the cross-head and rapidly open the circuit; the action of the compression spring $C^1$ is assisted by the extended spring $C^2$. The continued rotation of the motor again compresses the upper spring C until it is thrown out of gear by the circuit being broken at the contact $K^1$. The circuit will be completed through $K^2$, and the green lamp $J^1$ will be incandesced, showing that the circuit-breaker has been properly opened. The positive and negative 'bus bars shown at the bottom of the diagram, fig. 149, are excited by secondary batteries. The chances of this supply failing are, therefore, very remote. It will be seen, however, that, should it fail, none of the circuit-breakers will be affected, and the failure will be immediately shown by the extinction of the indicating lamps.

The circuit-breakers may be opened manually by means of a handle fitted to the projecting end P of the shaft carrying the ratchet wheel F.

The use of two circuit-breakers B and D, fig. 145, is to enable either of these switches to be tested. If one circuit-breaker only was used, it is evident that this could not be closed without connecting the generator on to the 'bus bars, but by closing one at a time the operation of the relay control may be frequently tested.

A modification of the switching arrangements at the New York stations has recently been installed in the Niagara Falls Power Co.'s new power-house. In this case the oil break circuit-breakers $C^1$ $C^2$ are placed over a subway which runs parallel with the generators. This subway carries the main 'bus bars $B^1$ $B^2$. Fig. 150 shows a sectional elevation across this subway.

The relay controlling switches and indicating instruments are arranged on panels A mounted on a raised gallery in the centre of the engine-room.

These panels are equipped with dummy 'bus bars similar to those used in the New York stations. In this case, however, the instruments are arranged in their proper positions in the dummy 'bus bar circuits. An objection raised against the New York system is that the switchboard attendant, in carrying out any switching operations, must first go to the operating desk or bench-board, as it is termed, and pick out the relay

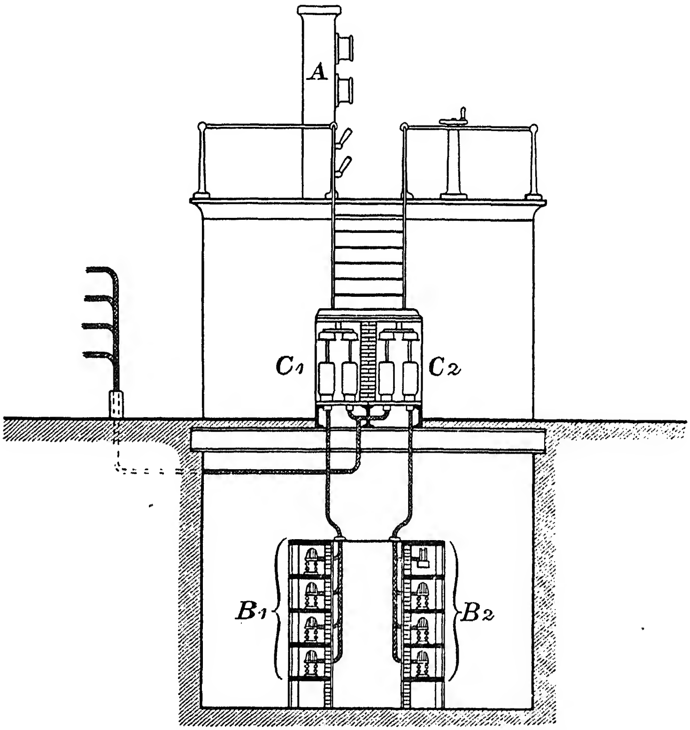



FIG. 150.—Section showing general arrangement of Niagara switchgear.

switch required, then taking his eye off this switch, he must select from a number of instruments in front of him on entirely separate panels the instruments involved in the operation he is about to effect. In the Niagara modification of this arrangement each generator or feeder panel constitutes a complete unit, and has on it all the instruments, relay switches, and dummy 'bus bars appertaining to that particular generator or feeder. The generator field rheostats and field switches are located under the switchboard gallery.

# CHAPTER VIII.

## GENERAL ARRANGEMENT OF CONTROLLING APPARATUS FOR LOW-TENSION SYSTEMS.

B.O.T. traction panel—Newington switchboard—M'Donald Road, Edinburgh, switchboard—'Glasgow': generator panels opposite each machine, feeder panels arranged on gallery above in groups of eight, with alternate groups of positive and negative feeders—'Hackney': generator and feeder panels arranged back to back—'Willesden': modification of 'Ferranti' high-tension board, with special selector switches for connecting generators to 'bus bars—'Kelvin and White' switchboard at Glasgow Exhibition: positive and negative panels placed one over the other—'Boston' switchgear, equipped with motor-operated switches.

ALTHOUGH the design of low-tension boards does not perhaps vary to quite the same extent as that of high-tension boards, there are, nevertheless, very marked differences in the general arrangement of the switching apparatus for controlling low-tension systems. The usual switchboard for low-tension three-wire systems, at any rate for small installations, consists of a number of slate or marble panels supported on an iron framework, with the instruments and switches, etc., on the face of the board, and with the 'bus bars and connections at the back of the board. The battery controlling switches and middle wire switches and instruments are as a rule mounted on a panel in the centre of the board, and the positive and negative generator and feeder panels are fixed respectively to the right and left of this centre panel.

### Board of Trade Traction Panel.

In the case of traction switchboards, the Board of Trade panel is usually located in the centre of the switchboard. This panel is equipped with the instruments necessary for making and recording the various tests specified in the Board of Trade regulations relating to this class of work. Fig. 151 shows Messrs Nalder Bros. & Thompson's standard B.O.T. panel. A is an ammeter for indicating the line leakage of any feeder. It is calibrated with two scales, one reading from ·001 to ·05 ampere, and the second from ·01 to ·5 ampere. B is a two-way switch enabling either of these scales

to be used. C is a multiple plug switch through which the leakage-indicating ammeter may be plugged on to any feeder. D is a recording voltmeter, range 0 to 10 volts, for recording the drop of pressure in the return rails. A second multiple plug switch $C^1$ is provided for connecting this voltmeter to different points on the rails. E is a recording ammeter, range 0 to 10 amperes, for recording the total earth current, *i.e.* the total leakage from the return rails. This ammeter is protected by an automatic switch F that short-circuits the instrument in the event of the total leakage-current exceeding the range of the ammeter. G is an ammeter, range 0 to 10 amperes, for testing the resistance of the earth plate to earth. This ammeter is connected in series with three Leclanché cells across the top contacts of the double-pole switch H. The earth plates, of which there are two, are connected respectively to the two middle contacts, and the earth wire from the recording ammeter E is connected to the lower pair of contacts. Normally this switch is placed with its handle down, thereby connecting the ammeter E to both earth plates. To test the resistance of the plates, the switch is connected to the upper contacts, the ammeter and battery circuit being thus completed through the plates.

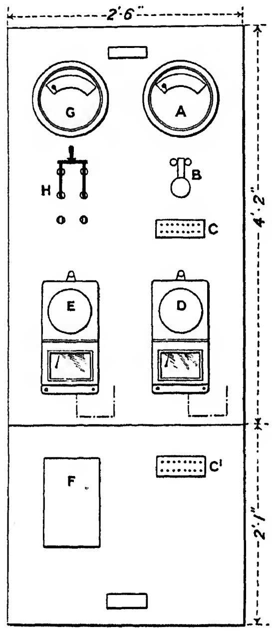


FIG. 151.—B.O.T. panel.

## Newington Vestry.

The switchboard supplied to the Vestry of St Mary, Newington, by the General Electric Co., illustrated in fig. 152, is a fairly representative example of the general arrangement of a lighting board of the type referred to above. A special feature of this design is the method by which the panels are supported, the object aimed at by the manufacturers being to have a standard series of parts, which could be put together with a minimum of labour. The framework of the switchboard is built up of a number of cast-iron sections, and the result obtained appears to combine strength, flexibility, and unlimited possibilities of extensions. On the centre panels are mounted the fifteen-point battery charge and discharge switches, also the middle wire connections and meters, and the balancer instruments and switches. Each of the four dynamo panels to the immediate right and left of the centre panel carries a main switch and duplicate fuse. The positive panels on the right are also equipped with

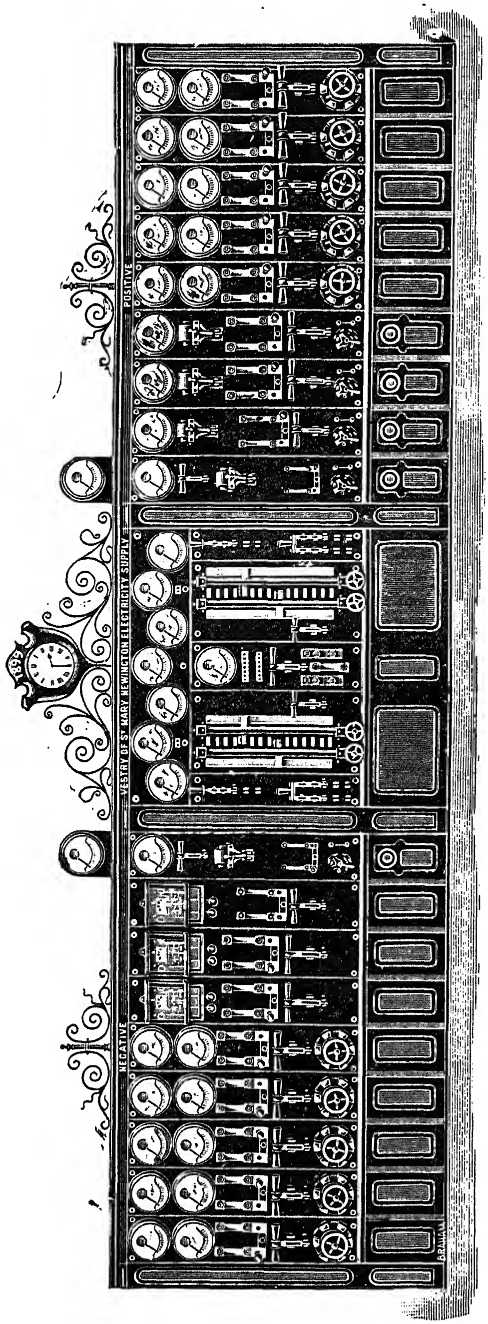



FIG. 152.—Newington Station L.T. switchboard.

ammeters, minimum current cutouts, and field regulators, and on the negative panels Aron watt-hour meters are fixed. The five positive and negative feeder panels at the extreme right and left of the board are provided with main switches, duplicate fuses, ammeters and voltmeters. The ammeters, in addition to the ampere scale, are calibrated with a volt scale showing the pressure required at the station end of the feeder for any given current, in order that the pressure at the feeding points may be maintained constant without the aid of pilot wires. Each feeder panel is also equipped with a regulating switch for inserting back E.M.F. cells in series with the feeder, by means of which the pressure on each feeder is regulated.

### Edinburgh.

In cases where a large number of generators and feeders have to be controlled, it becomes somewhat inconvenient to divide the positive and negative apparatus in the manner indicated above. The switchboard at the McDonald Road station at Edinburgh is an example of one method of dealing with this difficulty. This board was designed by Messrs Kennedy & Jenkin, consulting engineers to the undertaking. A separate panel is provided for each generator, or feeder, the total width of each panel being 1 foot 9 inches. Both the positive and negative connections from each generator, or feeder, are mounted on the one panel, the positive being on the left, and the negative on the right. By this means the attendant can see at a glance the state of any of the apparatus controlling a particular generator or feeder. Fig. 153 shows in plan and elevation the general arrangement of the switchgear and instruments.

The switchboard gallery, which is placed at one end of the engine-room, stretches the whole width of the building. This gallery, which is about 12 feet above the level of the engine-room floor, is 12 feet 6 inches wide. Of this space about 6 feet 6 inches is occupied by switches, instruments, pillars and hand-wheels, connections, etc. This leaves clear spaces in front and behind the panels of about 4 feet and 2 feet respectively.

All instruments, switches, etc., that require constant attention or manipulation are placed on, or controlled from, the main panels above the level of the gallery floor; but other apparatus, such as dynamo fuses, watt-meters, and instruments that only require occasional attention, are arranged on an extension of the main panels below the gallery floor. The panels consist of polished slate about 2 inches in thickness.

The main generators, balancers, etc., are arranged end to end in pairs, the centre line of each pair being at right angles to the side walls of the engine-room. The steam ends of the generators are adjacent to the side walls, thus leaving the commutator ends in the centre. A tunnel about 4 feet wide and 7 feet 6 inches high runs through the centre of the engine-room

from end to end. The conductors from each generator are led from the dynamo into this tunnel through earthenware pipes; they are then carried along the walls of the tunnel to the ground-floor panel of the switchboard, and are taken up this through the switches and instruments to the vertical bars of a three-way 'bus bar connector, by means of which any generator may be connected to either of three pairs of 'bus bars.

The generators are self exciting, and the pressure is regulated by means of resistances inserted in series with the shunt winding of each generator, hung just beneath the switchboard gallery. The necessary regulating

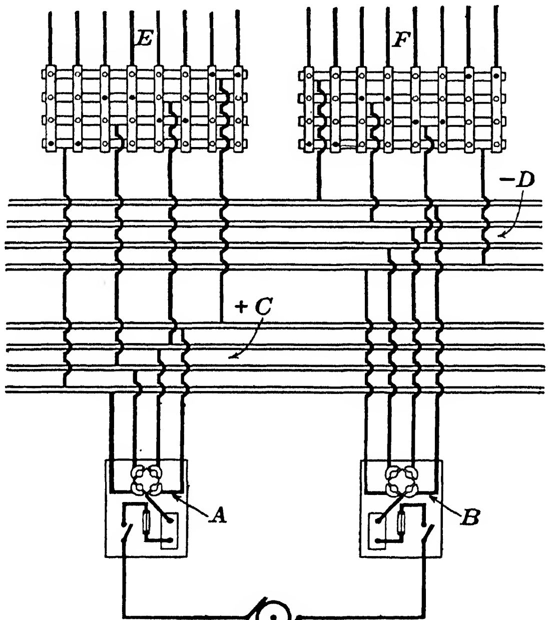



FIG. 154.—General arrangement of L.T. generator and feeder 'bus bars at the Glasgow lighting station.

switches are connected directly on to these resistances, and are controlled by a hand-wheel on the gallery, communicating with the regulating switch below by means of a spindle carried through the floor. A pointer shows the amount of resistance in circuit.

Some difficulty was experienced in designing a satisfactory method of signalling from the switchboard to the engine drivers, as no point of the station wall could be seen from all the engine stop-valves and governors. This difficulty has been got over by fixing on the top of the main board a large iron case containing several compartments. An opal glass in front of each compartment forms the front of the case. Behind each glass is

painted a number corresponding to each of the generators, boosters, etc. Each compartment contains an incandescent lamp, which may be switched on and off by means of a switch attached to the regulating resistance standard of the generator to be signalled. Similar cases, also divided into compartments, are fixed near the stop-valves of the generators, etc. These compartments are labelled with instructions such as,

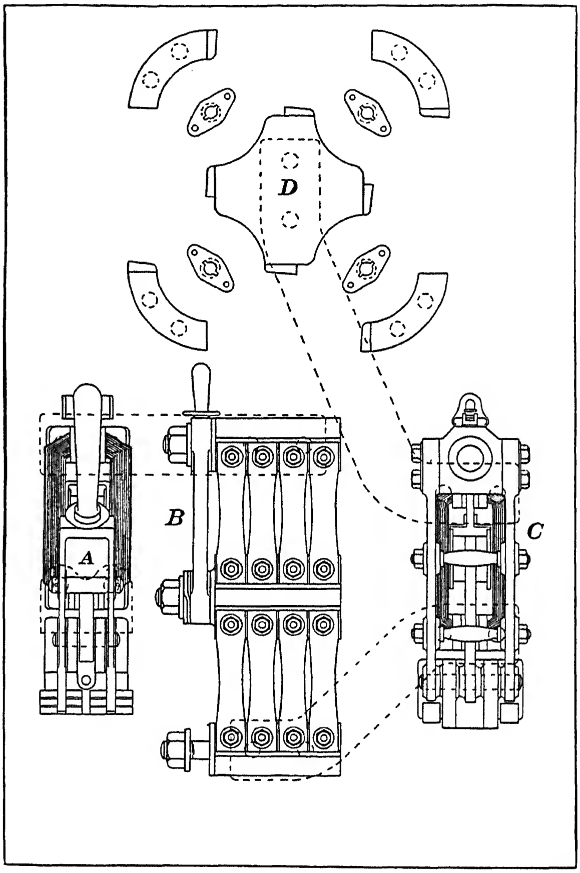



FIG. 155.—Positive generator panel (Glasgow).

"Start," "Up," "Steady," "Down," "Stop." It is obvious that the figures and words on the opalescent glass will only be visible when the lamp is lighted behind it. A loud bell draws the driver's attention to the fact that the switchboard attendant wishes to communicate with him. By looking at the signalling case over the switchboard he sees which generator is signalled, and on going to the stop-valve he receives his instructions from the signal-box attached to the same.

## Glasgow.

The arrangement of switchgear at the Glasgow lighting stations is widely different from that to be found in any other low-tension station. This was constructed to the design of Mr W. A. Chamen, the city electrical engineer. Fig. 154 illustrates the general scheme of connections.

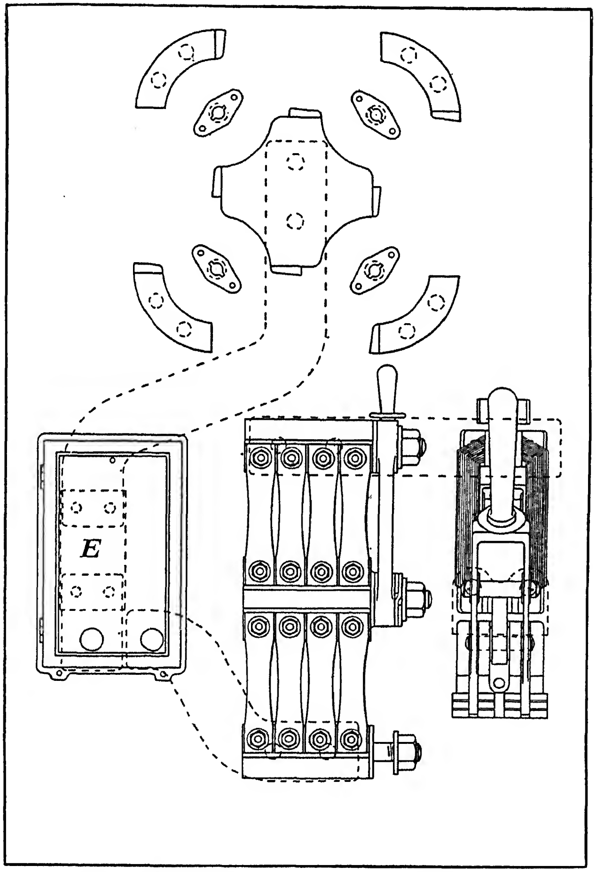



FIG. 156.—Negative generator panel (Glasgow).

Positive and negative generator panels A and B are placed on the ground floor directly opposite each generator. Connections are run from these to four sets of positive and negative 'bus bars C D supported beneath the feeder switchgear gallery. This gallery runs the entire length of the engine-room. The feeder panels E F are arranged in sections, each section dealing with eight feeders. The sections are arranged alternatively,

positive and negative. By this means the positive and negative connections are efficiently separated; at the same time the distance between the positive and negative connections to any one feeder does not exceed a few feet. The feeder panels are equipped with horizontal and vertical 'bus bars, by means of which any feeder may be plugged on to either of the four 'bus bars. These 'bus bars may, if desired, be maintained at different pressures, or may all be coupled in parallel.

Figs. 155 and 156 indicate the arrangement of apparatus on the positive and negative generator panels. The lead from the positive terminal of the generator is connected to one terminal of the main circuit-breaker A. The other terminal of the circuit-breaker is connected to the top of a duplex fuse. This duplex fuse consists of two fuses in series, either one of which may be short-circuited by the switch B. After leaving the fuse the current is taken through one of the author's discriminating cutouts C (see fig. 99). This cutout is constructed to open the circuit only in the event of its generator failing and tending to short circuit the 'bus bars. The top of the cutout is connected to the centre contact of the four-way plug connector D. By means of this connector the generator may be plugged on to any of the four 'bus bars referred to above. The arrangement of the negative panel is somewhat similar, the chief difference being that a recording ammeter E is inserted in the circuit instead of the discriminating cutout. The details of the plug connector are shown in fig. 157.

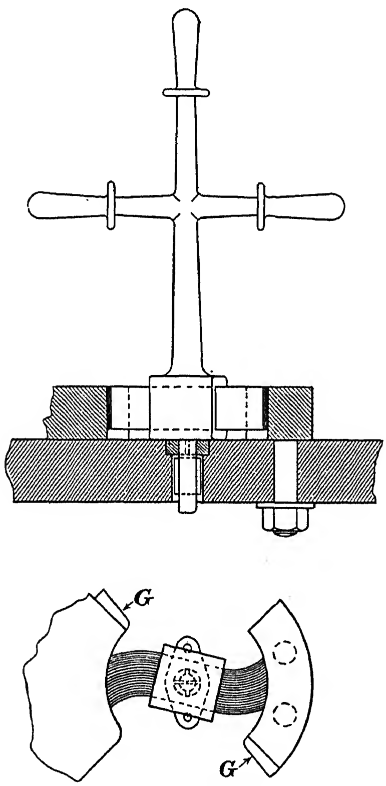



Fig. 157.—Details of Glasgow plug switch.

This plug consists of a laminated S-shaped contact carried on a removable key. The projection at the end of this key fits in the slotted key-way mounted in the slate base. The plugs can only be withdrawn by turning them through 180 degrees from the position in which they were inserted, and they cannot be turned beyond this. Although these plugs are not intended for making or breaking the circuit, carbon sparking pieces

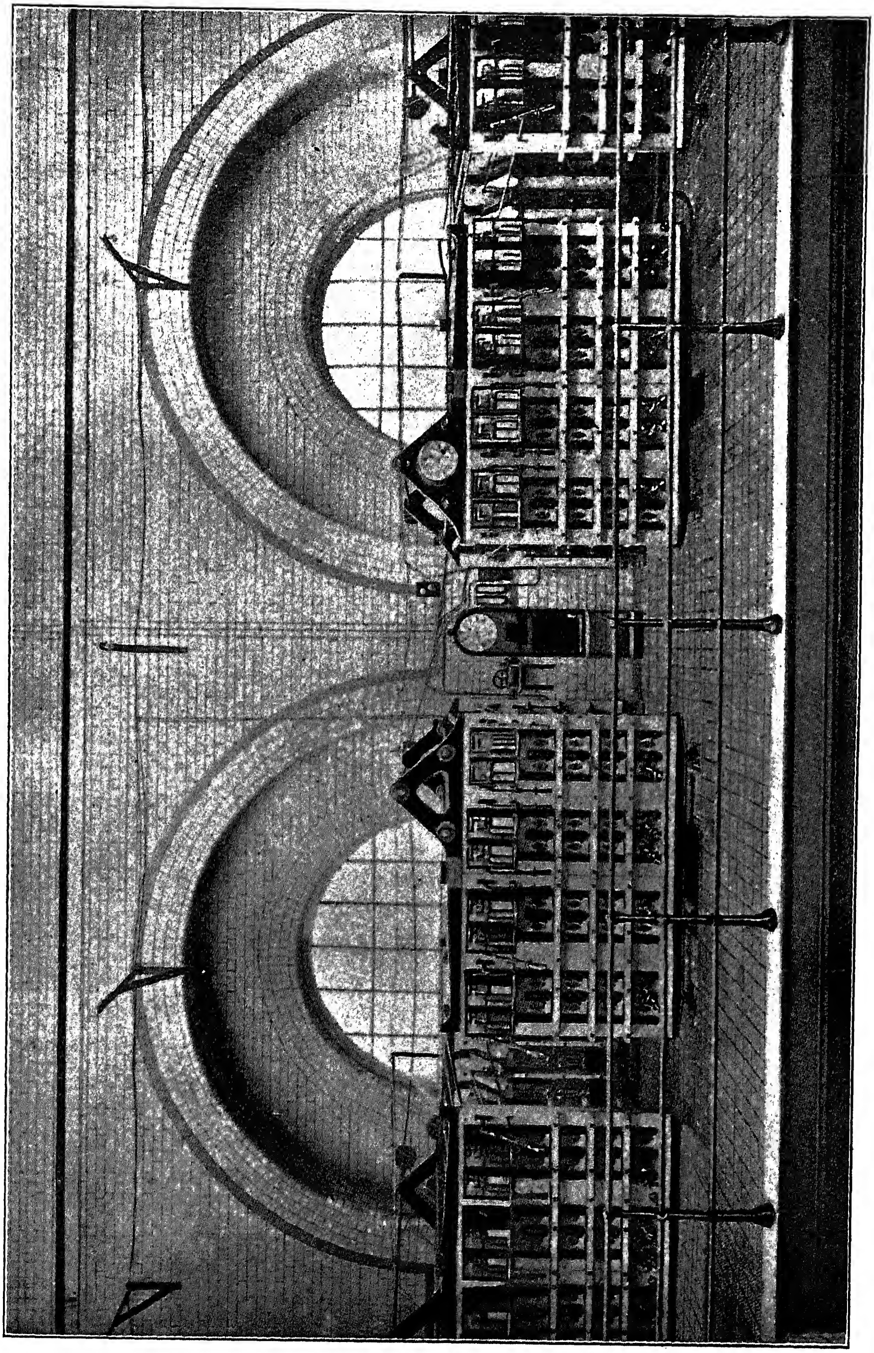


FIG. 158.—Front of feeder panels (Glasgow).

G are fitted on the contact plugs, so that they will not be injured if current is broken at this point.

Some of the feeder panels are illustrated in fig. 158, and a sectional view of these feeder panels is shown in fig. 159. Each feeder is connected to the lower contact plug of the duplex fuse A. Above this is mounted the emergency circuit-breaker B. The contacts of this circuit-breaker are divided into four blades. Three of these blades are directly connected to the shaft about which they turn, whereas the fourth blade is loose on the

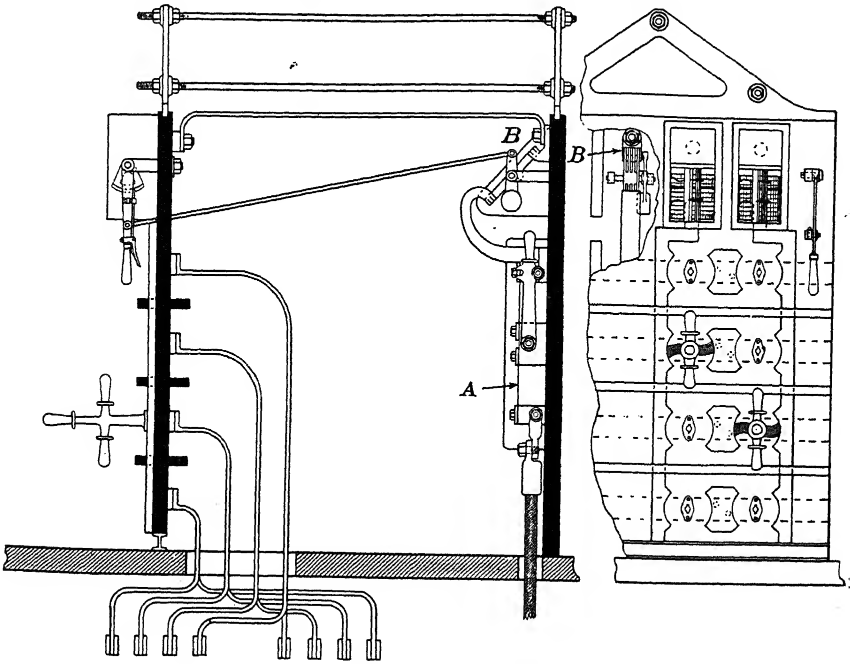



FIG. 159.—Section through feeder panels (Glasgow).

shaft. By this arrangement a comparatively quick break may be obtained. The first effect of pulling the operating handle is to break the circuit through the three rigidly connected blades, leaving the supply momentarily maintained through the remaining blade. The circuit is finally broken by the loose blade being knocked out by the weight on the end of the operating lever. To prevent burning of the contacts, the final spark is taken by carbon blocks.

The front panel carries the operating handle of the emergency circuit-breaker, the contact blocks for the plug connectors, and a combined recording ammeter and voltmeter for each feeder. The latter extremely useful combination was made by Messrs Kelvin and White. The advantage of having a daily record of the current and E.M.F. of each

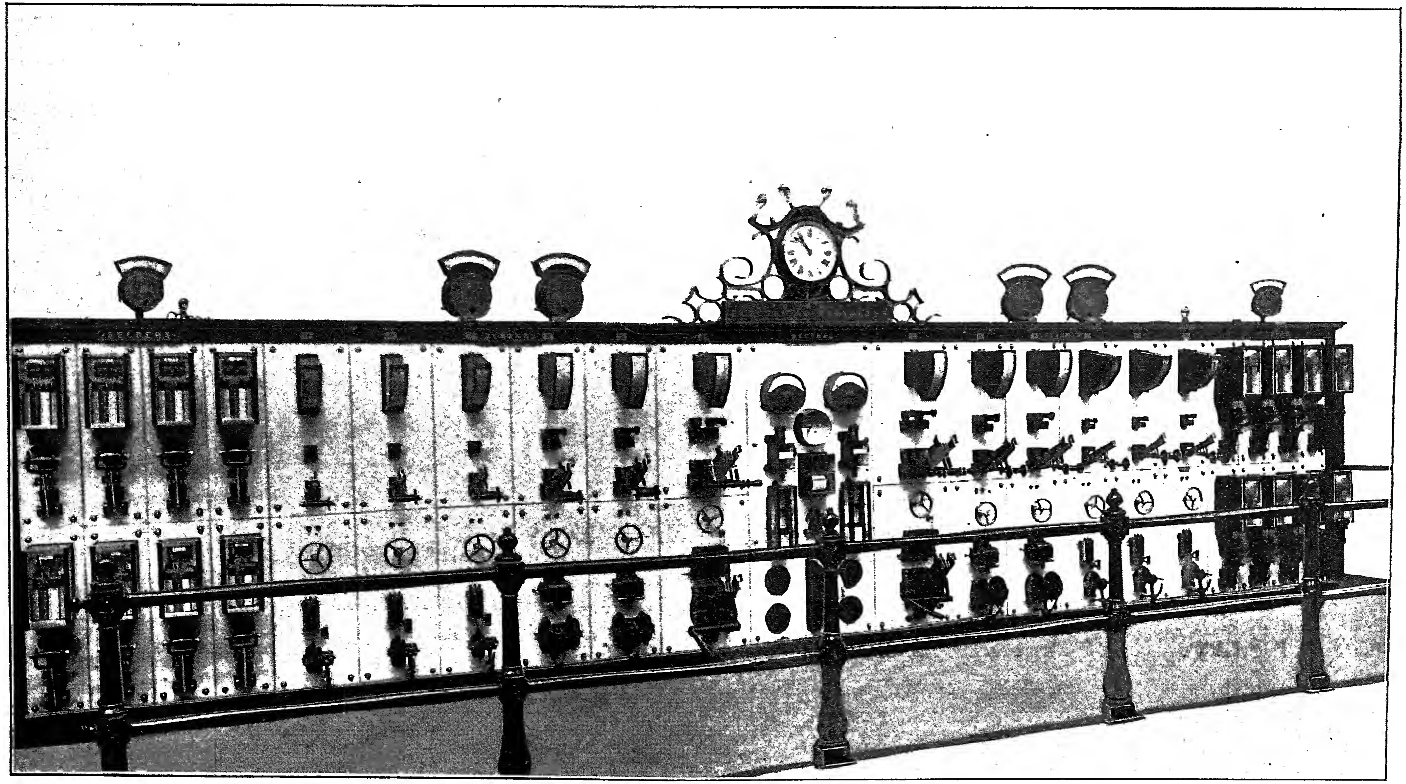


FIG. 160.—Kelvin and White's Glasgow Exhibition L.T. switchboard.

feeder on one chart is obvious. The rotating drums of these instruments are all actuated by a pawl and ratchet movement controlled by one regulating clock situated in the centre of the switchboard gallery. These instruments, in addition to recording the current and pressure, also indicate the same at each instant on a vertical scale.

A feature of this switchgear is the magnitude of the conducting circuits. Provision has been made for dealing with no less than forty pairs of feeders, and each of the feeder connections is designed to carry 1000 amperes, with a wide margin. All the contact blocks, etc., are of solid forged copper, and are very massive. It is stated that over 40 tons of copper were used for the main 'bus bars alone.

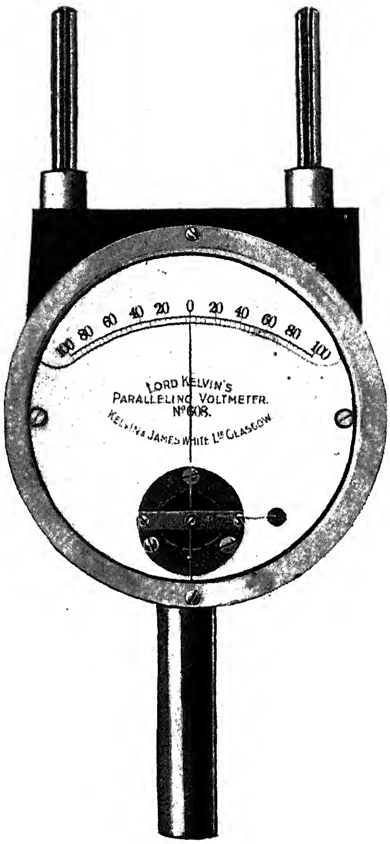



FIG. 161.—Paralleling voltmeter.

The switchboard gallery itself is of novel construction, being built of iron and paved with glass blocks. The glass projects above the iron in such a manner that attendants are thoroughly insulated from earth, and the use of rubber mats is therefore unnecessary. A further advantage of this construction is that the generator panels below the switchboard gallery are efficiently lighted.

## Kelvin and White's Switchboard.

The supply of the whole of the current for the Glasgow International Exhibition in 1900–1 was controlled by the switchboard illustrated in fig. 160. Panels are provided for twelve generators and eight feeders, dealing in all with 3000 amperes. The middle panel is fitted with bar and dynamo voltmeters, electro-static voltmeters, recording voltmeters, an earth current recorder, middle wire and earth ampere gauges, voltmeter switches, etc.

Balancing and pilot illuminated dial voltmeters are mounted on swivel brackets on the top of the switchboard frame. Positive and negative panels for each feeder are mounted, one directly above the other, immediately to the right and left of the middle panel, all the positive panels being at the top. Each positive generator panel is equipped with an ammeter and main switch, and each negative panel carries a Ferguson-White return current cutout, a dynamo field regulating hand-wheel, and a pair of sockets for a Kelvin portable paralleling voltmeter. An illustration of this voltmeter is shown in fig. 161. Its use does away with a large number of small wires between the paralleling voltmeters and switches, which are often a source of trouble. All the positive feeder panels are fixed at the left end of the board, and the corresponding negative panels at the right end. Each panel is fitted with a switch and a combined recording ammeter and voltmeter similar to that described above. These recorders are all controlled by the clock erected above the top of the board. The whole of the panels are of polished white marble carried on a steel framework.

## Ferranti Low-Tension Switchboard.

Messrs Ferranti have recently turned their attention to constructing switchboards for controlling low-tension systems. Fig. 162 is a section and front elevation of a portion of a switchboard they have constructed to Mr E. T. Ruthven-Murray's specification for the Willesden Corporation. The general design of this board is somewhat similar to the standard Ferranti high-tension board described in the previous chapter.

A special feature of the arrangement, suggested by Mr Ruthven-Murray, is the 'bus bar change-over switch for connecting the respective generators and feeders to any one pair of the four pairs of 'bus bars provided. This arrangement is shown in fig. 162.

The positive terminal of each generator is connected to the release coil A of a maximum and reverse current cutout. This coil is carried in a case, which is provided with contacts somewhat on the lines of the standard Ferranti fuse. The operation of removing it and replacing it by another is, therefore, very simple. The connection to the positive 'bus bars $D^1$ $D^2$ $D^3$ $D^4$ is completed through the switch B, an ammeter C, and the four-way switch referred to above. The connection from the negative terminal of the dynamo is carried directly to the four-way switch E in the top compartment of the switchboard. Voltmeters F for various purposes are mounted above the switchboard. These voltmeters are carried on miniature tram rails G, one of these rails being divided into sections, and the circuits across which potential readings are required are connected to different sections of this divided rail. By merely pushing the

voltmeter along these rails to the desired section any reading required may be obtained. The generator field switches H and field ammeters J are mounted on a panelled desk in front of the switchboard. Hand-wheels K for regulating the field resistances are mounted on shafts connected to the rheostats situated below the gallery floor. Receptacles are also provided on the top of this desk panel for receiving the contacts of a portable paralleling voltmeter L. Somewhat similar panels to the

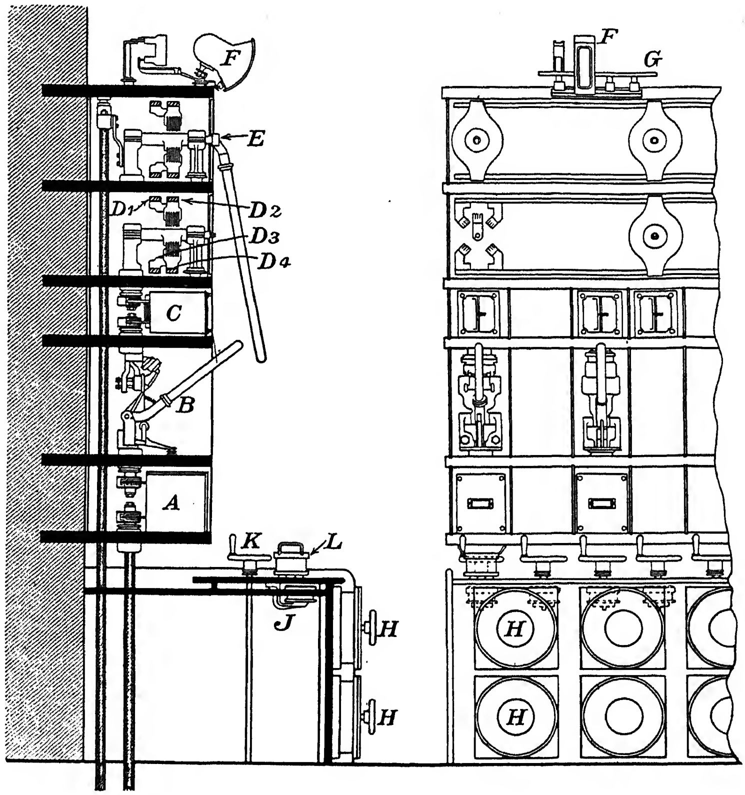



FIG. 162.—Section through Willesden L.T. switchgear.

generator panels shown in fig. 162 are provided for the feeders, boosters, and balancing circuits.

A section of another Ferranti low-tension board is shown in fig. 163. This board was constructed for the Hackney Corporation to the specification of the consulting engineer, Mr Robert Hammond. A feature of this board is the back-to-back arrangement of the generator and feeder panels.

The combined main switches and automatic cutouts used in the generator circuits are of the Ferranti loose handle type. Provision is

made for plugging each generator feeder on to any one of the four pairs of 'bus bars provided. Fig. 164 is a front view of the generator switchgear.

The battery regulating switches can just be seen at the top of this

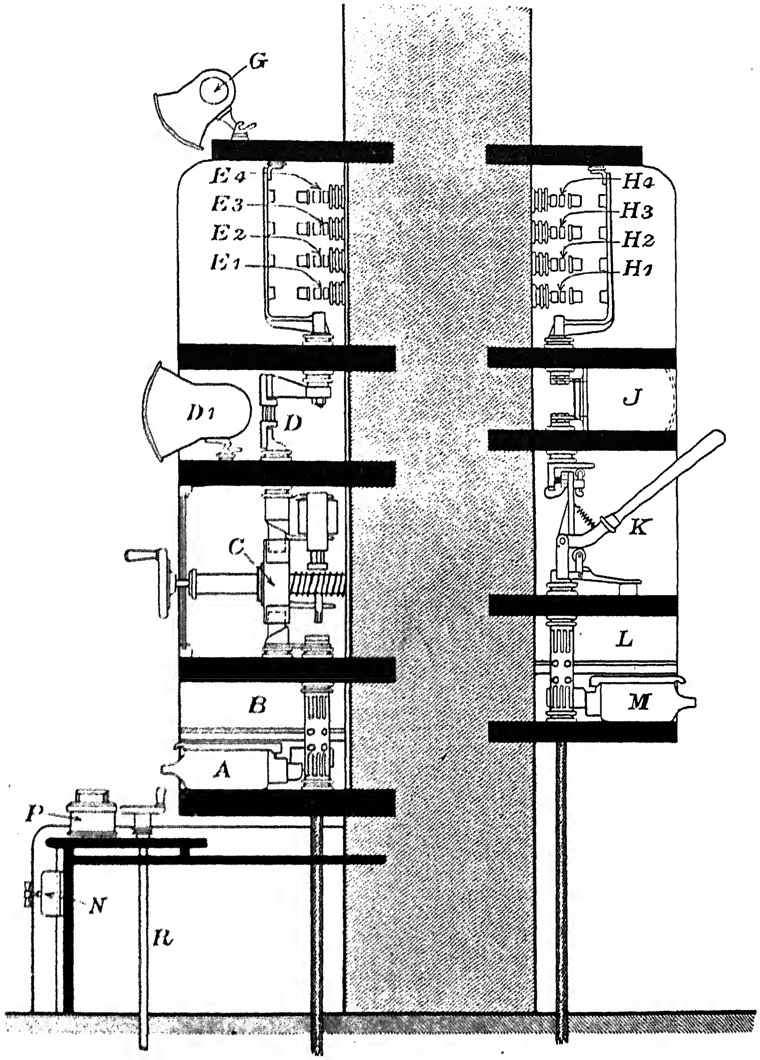



FIG. 163.—Section through Hackney L.T. switchgear.

photograph, supported from the ceiling over the switchboard gallery. These switches are controlled by handles fixed at the lower extremities of vertical shafts supported in the centre of the switchboard. Bevelled wheels at the top of these shafts engage with horizontal shafts upon which

the worm wheels driving the screw shaft of the regulating switches are fixed.

The positive and negative generator panels are fixed respectively to the

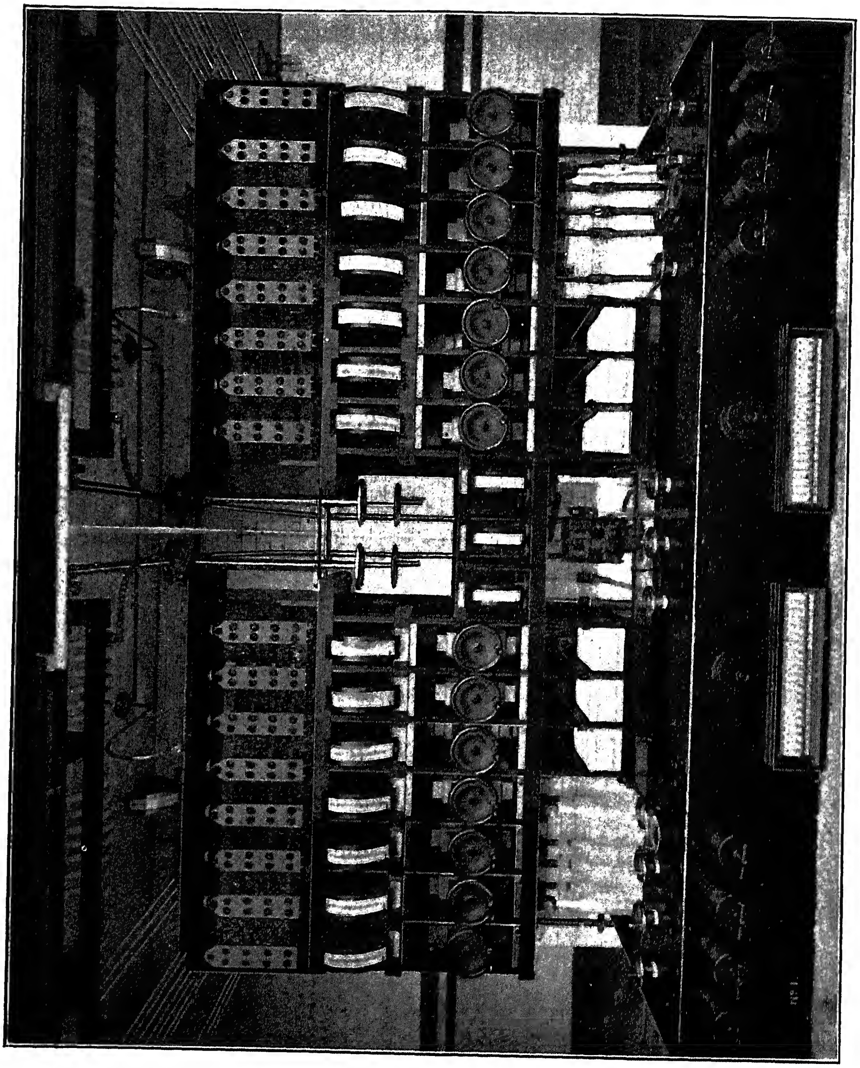


FIG. 164.—Front view of Hackney board.

right and left of the battery controlling gear. In addition to the field switches on the front of the panelled desk, at the bottom of the switchboard two cases are fixed, each containing twenty fuses, in which the feeder pilot wires terminate. A twenty-way pilot wire voltmeter switch is fixed above each set of fuses.

Fig. 165 is a reproduction of a photograph taken from one end of the switchgear, showing the generator gear on the left, and the feeder gear on the right of the illustration.

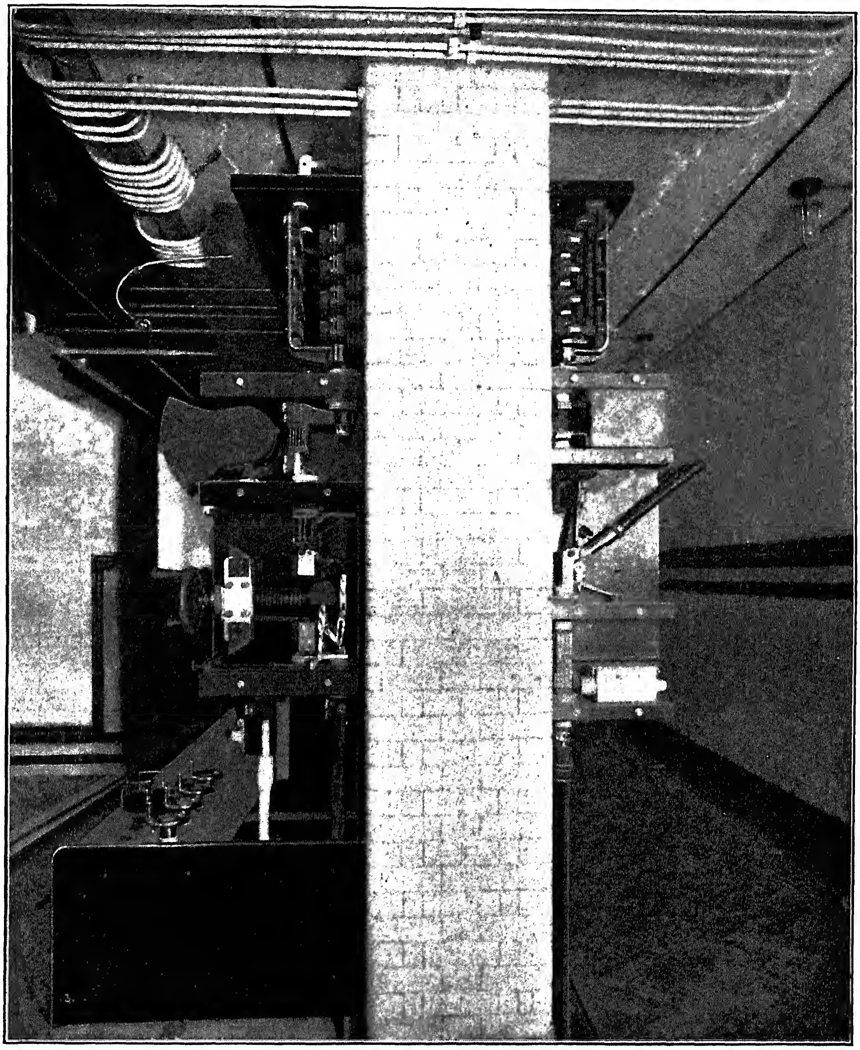


FIG. 165.—End view of Hackney board, showing back-to-back arrangement of generator and feeder panels.

## Boston, U.S.A., Switchgear.

An interesting example of American practice in the arrangement of low-tension switchgear is to be seen at the Atlantic Avenue station, Boston.

The generating plant at this station is divided into two distinct engine-rooms, and the switches and other controlling apparatus are arranged in a separate room. This switchboard room is entirely shut off from the engine-rooms, but the switchboard attendant can signal to the attendants in either engine-room by means of dial posts of the Cory system of engine telegraphs. Each signalling set consists of one disc signifying the engine or booster in question, and a second disc denoting the instructions to be given regarding that unit. A sectional view of the switch-room is

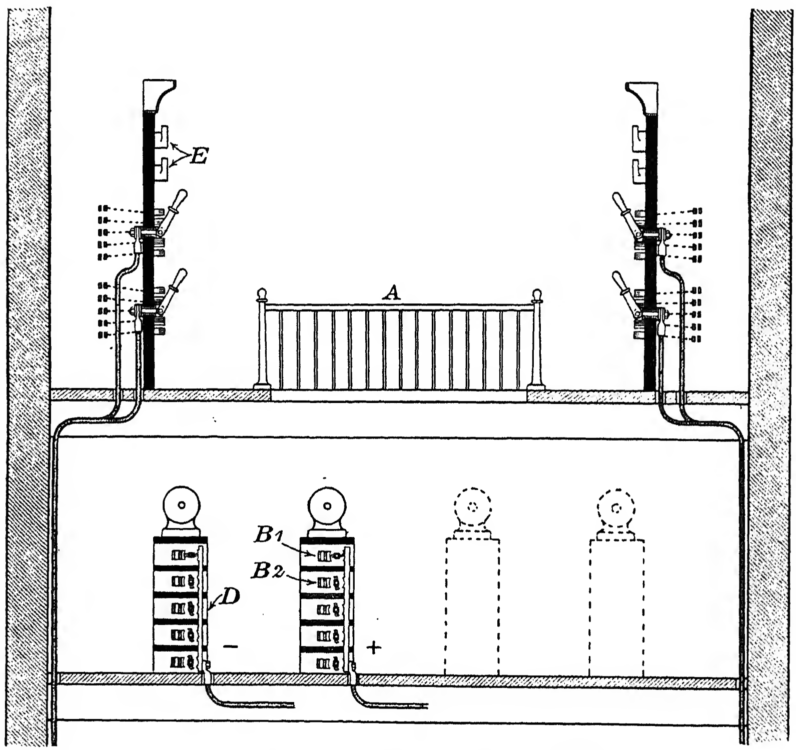



FIG. 166.—Section through Boston L.T. switch-room.

shown in fig. 166. All the recording and indicating instruments are fixed on a gallery running all round the switch-room, the apparatus controlling the generators being on the section of the gallery at one end of the room, with the feeder panels on each of the side galleries. The actual generator switches are placed on the ground floor, and are motor controlled by relay switches on an operating desk situated near the generator section of the gallery. The operating desk and instruments for the generator section are not shown in fig. 166, but the approximate position of this apparatus is indicated by the letter A.

There are at present forty motor-driven main generator switches. These are arranged in two rows parallel with the side galleries, there being twenty positive switches in one row, and twenty negative switches

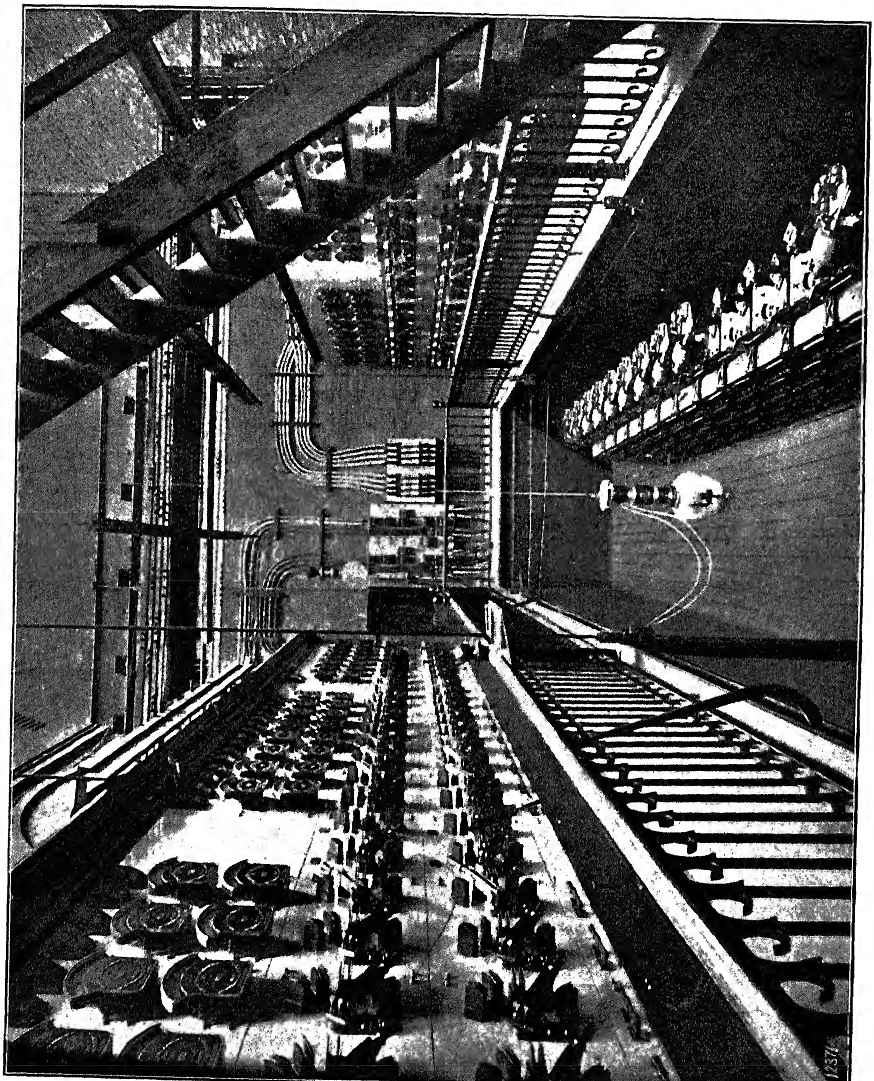


FIG. 167.—Interior view of Boston switch-room.

in the other row. Room is left for two more rows of switches in the positions where they are shown dotted. These switches are used to connect the positive and negative leads from the generator on to either

pair of the five pairs of 'bus bars provided. Each generator lead is connected to the vertical bar D of one of these switches, and the five 'bus bars $B^1$ $B^2$, etc., are run horizontally, one above the other, from end to end of each row of switches. These 'bus bars, which are maintained at different pressures, are connected by heavy flexible cables to the corresponding 'bus bars behind the feeder panels on each side of the gallery. Connections are run from the feeder 'bus bars to the respective contacts of multiple blade five-way switches (see fig. 17, Chapter II.). One of these switches is provided for each of the positive and negative connections to every feeder. Above the feeder switches are ammeters E of both the Weston and Thomson astatic types in series with the feeders. The potential at the distributing end of the feeders is indicated by pilot wires connected to a common voltmeter through a large multiple contact voltmeter switch.

Some of the large motor-driven switches on the ground floor are designed to carry a current of 7000 amperes. The construction of these switches is such that it is impossible to connect one generator to two 'bus bars simultaneously. If a generator is already connected to one of these 'bus bars, and the relay switch controlling the motor is put in the position to connect this generator to another 'bus bar, the motor will close the second switch, but before doing so it will automatically open the switch through which the generator was previously connected. These switches are provided with a magnetic blow-out which breaks any arc that may be formed on opening the switch.

A general view of the switchboard room, taken from the operating desk, is shown in fig. 167.

# CHAPTER IX.

## EXAMPLES OF COMPLETE INSTALLATIONS.

'Edinburgh': low-tension continuous current three-wire system; general arrangement of apparatus, method of obtaining different pressures for long and short feeders, battery charging and regulating arrangements, and signalling arrangements—'Hull': high-tension, constant pressure, continuous current system; rotary transformers in sub-stations controlled by special long-distance switches and pilot wires from generating station—'Hastings': single phase, alternating current system; construction, general arrangement, and equipment of sub-stations; area of supply divided into two large networks, each network being subdivided into a number of small networks interconnected at sub-stations only; arrangements for cutting off the whole of the high-tension feeders and transformers during the hours of light load.

It would be quite beyond the limited scope of this work to fully describe the large number of various systems of electrical distribution in use at the present time. An attempt will, however, be made in this chapter to briefly indicate the broad principles underlying some of the different systems.

A few years ago there were practically only two systems of distribution, namely, the low-tension continuous current system, and the high-tension alternating current system. It was thought by many at that time that the former system could only be efficiently used for very small and compact areas of supply. Within recent years the field for low-tension distribution has been enormously increased, in the first place by the use of the three-wire system of distribution, invented by the late Dr John Hopkinson, and in the second place by the commercial introduction of the 200-volt lamp. The object of both these improvements has been to increase the pressure of distribution.

The effect of doubling the pressure is of far greater importance than appears at first sight. The area that can be efficiently supplied by a given pressure is limited by the difficulties of regulation, the Board of Trade regulations stipulating that the maximum variation of pressure from the declared pressure shall not exceed 2 per cent.

Now, with a given load, the effect of doubling the pressure in any conductor is to halve the current density. The voltage drop per 100 yards run is therefore halved, and as a consequence the length of the conductor may be doubled for a given drop of pressure; but if the declared pressure is also doubled, the voltage drop in the conductor may also be doubled without exceeding the stipulated percentage variation of pressure. It will be seen, therefore, that the effect of doubling the pressure is to permit the use of feeders four times the original length. If the generating station is situated in the centre of the area of supply, this station can efficiently supply at a declared pressure of 200 volts an area sixteen times as great as it could deal with at a declared pressure of 100 volts.

By the use of the three-wire system referred to above the difference of potential between the conductors may be doubled without increasing the declared pressure across consumers' lamps, or if desired, this system may be

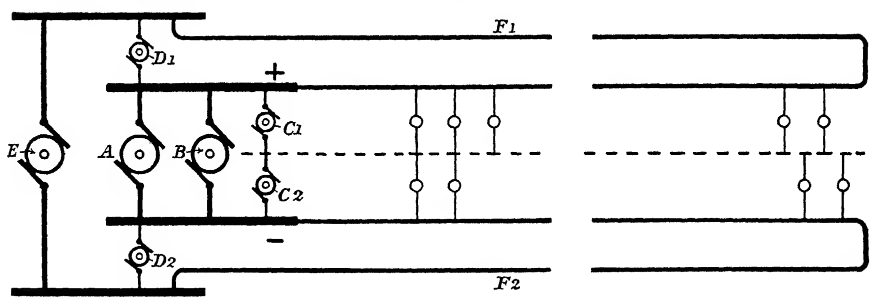



FIG. 168.—Diagram illustrating three-wire system of distribution and method of boosting up pressure for long feeders.

combined with the use of high-voltage lamps, and the efficient area of supply correspondingly increased. By means of the three-wire system consumers' lamps are virtually connected two in series, as indicated diagrammatically in fig. 168. For this purpose installations have to be balanced so that the load directly connected to one main shall be approximately equal to the load directly connected to the other main.

It is, of course, impossible in practice to arrange that these loads exactly balance each other under all conditions; if, therefore, lamps were coupled in this way across a two-wire system, it is obvious that the resistance of the lamps on the side most heavily loaded will be considerably lower than the resistance of the lighter load, and as a consequence the E.M.F. across the latter will be much higher than across the former, and the maximum permissible variation of pressure will in consequence be greatly exceeded. To overcome this difficulty, Dr Hopkinson suggested that the common point of connection between the lamps in series should be connected to a third wire, carried back to the generating station, and that two small generators

coupled in series should be provided to supply the out-of-balance current. If, for instance, in fig. 168 the load between the positive conductor and middle wire is 2200 amperes, and that between the negative conductor and middle wire is 2000 amperes, the main generators A and B will supply the balanced current of 2000 amperes on the positive side, and the balancer $C^1$ will supply the 200 amperes out-of-balance current on this side. If now 400 amperes is switched off the positive side, and the load on the negative side remains as above, the main generators A and B will now be required to supply the 1800 amperes balanced load, and the negative generator $C^2$ will supply the 200 amperes out-of-balance current on this side.

It is obvious that the middle wire is only required to carry the out-of-balance current, and as a consequence the sectional area may be very much less than that of the outer wires. In many cases the middle wires are not brought back to the generating station, two-wire feeders being used, and the balancing generators are driven by motors situated at convenient centres in the distributing areas.

In very large and heavily loaded districts it is customary to provide two or more sets of 'bus bars in the generating station, and to maintain these at different pressures. The very long feeders $F^1$ $F^2$, fig. 168, supplying outlying districts are connected to 'bus bars at higher pressures, and a drop of pressure considerably greater than the variation allowed by the Board of Trade regulations is then permissible, as these regulations only refer to the variation at consumers' terminals. The higher pressure on these 'bus bars may be maintained either by connecting them to independent generators E, or by inserting boosters $D^1$ $D^2$ between the sets of 'bus bars, these boosters being constructed to give the few extra volts required.

## Edinburgh (Low-Tension Direct Current).

Edinburgh is supplied by two distinct generating stations a considerable distance apart. Both stations feed, however, the same common area of supply, and are therefore interconnected. The details given below refer particularly to the station at McDonald Road.

Fig. 169 is a diagram of the connections between the generators, main 'bus bars, and feeders. The generators G are coupled to the main 'bus bars through an ampere hour-meter A, double-pole duplex fuses $F^1$ $F^2$, double-pole carbon break switches $S^1$ $S^2$, a dynamo ammeter $D^1$. and plug 'bus bar connectors $P^1$ $P^2$.

A multiple way voltmeter switch K is connected to each terminal of the double-pole main switch, by means of which a pair of voltmeters $V^1$ $V^2$, common to all generators, may, by one movement of this switch, be con-

nected respectively across the poles of the generator and the 'bus bars on which the generator is plugged. The advantage of this arrangement is that there is no chance of the voltage of the wrong bars being taken. To connect a generator on to the 'bus bars, the E.M.F. of the incoming

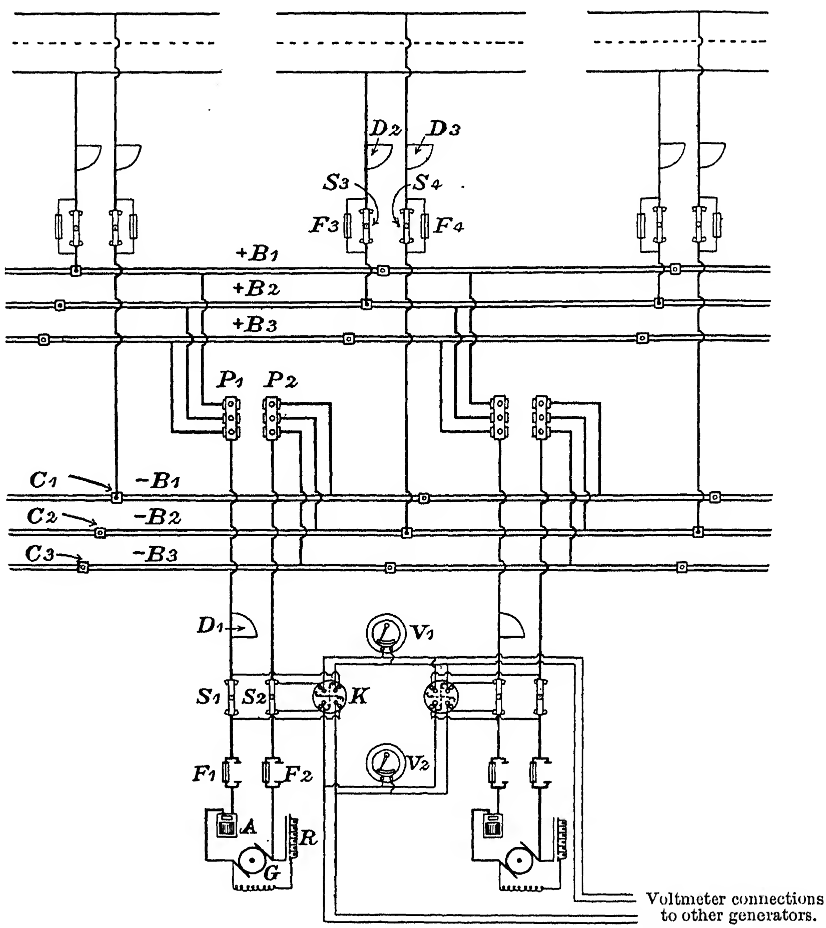



FIG. 169.—Diagram of connections of generator and feeder panels (Edinburgh).

generator is adjusted until both voltmeters read alike. The main switch is then closed.

It will be obvious, on referring to fig. 169, that the simultaneous closing of any two voltmeter switches connected to the one pair of voltmeters would parallel the generators through this connection. To prevent this the voltmeter switches are so constructed that they can only be turned on and off by a key, and only one such key is provided for each pair of volt-

meters. As this key cannot be withdrawn when a switch is closed, it is impossible to close two switches simultaneously.

The dynamo fuses are arranged with double contacts, so that, if it is required to examine a fuse or to increase or decrease the sectional area of a fuse when the particular generator to which it is connected is working, it is merely necessary to insert another fuse before withdrawing the one to be altered.

The feeders are equipped on each pole with single-pole carbon break switches $S^3$ $S^4$, the positive and negative switches being capable of separate and independent control. Thus a feeder may be disconnected on the positive side, and left connected on the negative side, or *vice versa.*

The feeders are taken from the 'bus bars through the ammeters $D^2$ $D^3$ and single-pole switches referred to above from the top of the board to the wall behind the panels; they are then carried along the surface of the wall, and finally run down into the feeder tunnel. This tunnel extends about a mile towards the centre of the city. From the further end of this the feeders are taken to different points of the distributing network.

No fuses or cutouts are used on the feeders. Each feeder switch is, however, shunted by a light fuse $F^3$ $F^4$. This fuse momentarily carries the current after the main switch is opened, and is intended to interrupt any arc formed on opening a heavily loaded circuit.

The middle wire or earthed conductor $L^1$, fig. 170, generally called the third wire, is brought in through an ammeter $D^4$, and is connected to the third wire 'bus bar. This is in turn connected to earth through an ammeter $D^5$ and meter $A^1$.

Any feeder may be connected on to either of the three pairs of 'bus bars by means of flexible cables and coned connectors $C^1$ $C^2$ $C^3$, fig. 169. All the feeders within a certain radius are connected to the middle 'bus bars $B^2$, and the longer feeders are connected to the top bars $B^1$. These bars are in consequence termed, respectively, the short bars and the long bars. The third or bottom bars $B^3$ are reserved as spare bars.

When the feeders are fully loaded it is necessary to maintain a considerably higher pressure across the long feeders than is required across the short feeders, to allow for a greater drop of pressure in the former, due to their increased length (see fig. 168). This is provided for by running the long bars at higher pressure than the short bars; for instance, in order to obtain an even pressure throughout the entire system of distribution, it may be necessary to supply the long feeders at a pressure of, say, 540 volts, while the short feeders only require 500 volts. This increased pressure may, of course, be obtained by regulating the generators connected

to the long bars to give a higher E.M.F. than those connected to the short bars. It is obvious that the increased drop referred to will only occur during the hours of heavy load; that is to say, for many hours every day the pressure required across the long bars will be identical with that across the short bars, and during these hours it will be neither necessary nor advisable to run two systems. To obviate so doing, positive and negative bar connecting switch panels are provided. These are equipped with bar coupling switches $S^5$ $S^6$, fig. 170, ammeters $D^6$ $D^7$, fuses, three-way plug connectors, and voltmeters, the connections being as shown in fig. 170.

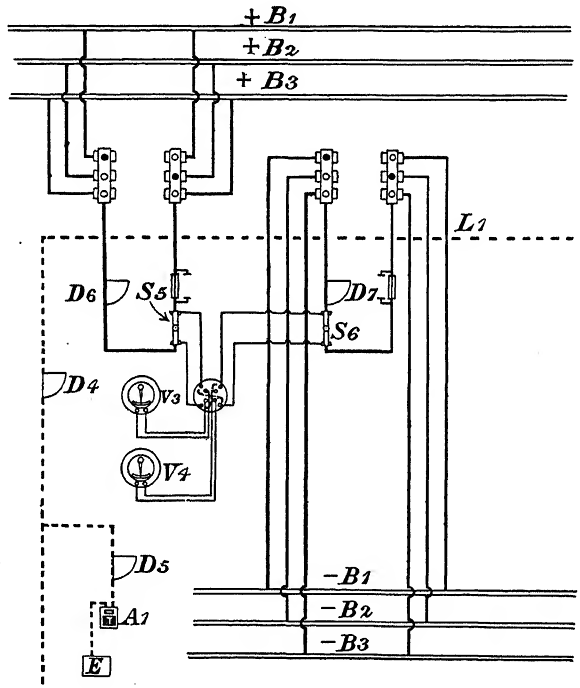



FIG. 170.—Connections of bar coupling and earth panels (Edinburgh).

In this, as in all other cases, positive and negative connections are both mounted on one panel; they are, however, shown separate in fig. 170, with the object of attaining greater diagrammatic clearness.

During the hours of light load, plugs are inserted as shown black in fig. 170, and the bar coupling switches are closed. Under these conditions the long and short bars may be treated as one bar; consequently all the feeders may, if the load is small enough, be supplied from one generator. When it becomes necessary to raise the pressure of the supply to the long feeders, the generators are plugged on to both long and short bars, and made to take their proper proportions of load, until the ammeters $D^7$ on

the bar coupling panels fall to zero. The bar coupling switches are then opened, and the supply to the two systems is kept entirely separate. Each system may now be regulated to give the required pressure at the feeding points.

The bars may be again reconnected when the load has fallen sufficiently to make it unnecessary to maintain two different pressures at the generating station. For this purpose the voltage across the long and short bars is adjusted until the readings are identical; this is shown by the voltmeters $V^3$ $V^4$ connected across the top and bottom of the bar coupling switches falling to zero. When this occurs the coupling switches may be closed.

It may sometimes occur that the load on, say, the positive long bar drops sufficiently to enable the long and short bars to be coupled on the positive side some considerable time before it is possible to couple the negative bars; in that case the positive bars may be connected and the long bar on the negative side left disconnected from the negative short bar, and maintained at the higher pressure required.

It will appear from the above that it may be frequently necessary to run a generator on each system only half loaded; that is to say, this double system may involve the running of an additional generator to that which would be required if the whole of the feeders were supplied at one pressure. To reduce the loss this would entail, equalising boosters are provided. The connections to these equalisers are shown in fig. 171.

A motor M is connected, through a motor-starting switch S S, fuses, etc., across the positive and negative short 'bus bars. Small generators $G^1$ $G^2$ are coupled on to each end of the shaft of this motor, these generators being each capable of generating 800 amperes at 25 volts. Arrangements are provided for connecting one generator between the long and short bars on the positive side, and the other between the long and short bars on the negative side.

Let it be supposed that the total output of the station at a given time is 6000 amperes, and that of this, 2400 amperes are being supplied to the long bars at a pressure of 540 volts, and 3400 amperes to the short bars at a pressure of 500 volts. Let it further be assumed that the output of the generators is 1000 amperes each. To meet the above demand it will be necessary to run three generators on the long bars and four generators on the short bars—that is to say, altogether seven generators will be required; whereas, if the two bars were coupled together, the whole of the work could be done by six generators. Obviously what is required is that 400 amperes be taken off the long bars and put on to the short bars; it will then only be necessary to run two generators, instead of three, on the long bars. The way in which this transference is effected will be understood on reference to fig. 171.

The motor of the equalising booster is run up to speed by closing the motor-starting switches S S. The field switch $F^5$ of, say, the positive generator is then closed, and the resistance in series with the field of this generator is adjusted until the pressure across it is identical with the difference of pressure between the long and short positive 'bus bars, as indicated by the two 'bus bar and booster

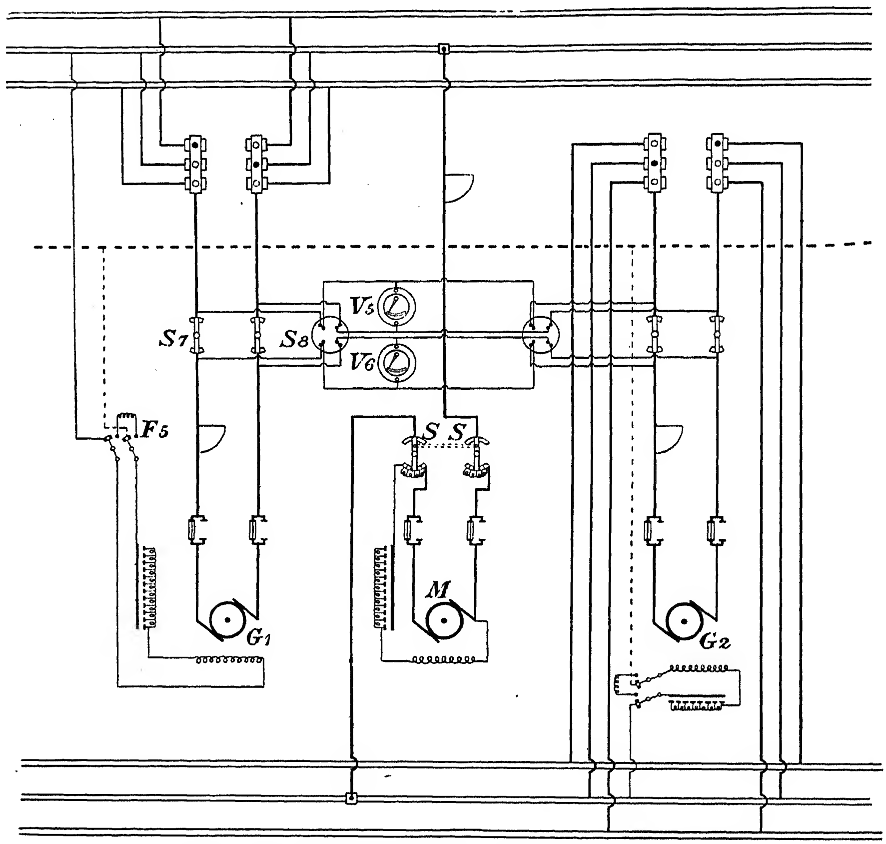



FIG. 171.—Connections of equaliser or booster panels (Edinburgh).

voltmeters $V^5$ $V^6$ connected across the main switches. When this occurs the switches $S^7$ $S^8$ connecting the booster between the long and short bars on the positive side may be closed. The resistance in series with the field of this generator may now be further reduced until the ammeter in the booster circuit indicates that the 400 amperes required are being supplied to the long bar from the short bar. The above operation is then repeated on the negative side.

If the efficiency of the equalising booster be, say, 80 per cent., the total load on the short bars will now be as follows :—

| | |
|---|---|
| Current supplied to the short feeders . . . . | 3400 amperes. |
| Current supplied through the booster to the long feeders . . . . . . . . . | 400 ,, |
| Current taken by motor when boosting up, 400 amperes, 40 volts, at an efficiency of 80 per cent. | 40 ,, |
| Total current to be supplied by generators connected to short bars . . . . . . . . | 3840 amperes. |

Whereas the load on the long bars will now be reduced as follows :—

| | |
|---|---|
| Current supplied to the long feeders . . . . | 2400 amperes. |
| Less current received from the short bars . . . | 400 ,, |
| Total current supplied by generators feeding long bars | 2000 amperes. |

Thus it will be seen two generators only will be required for the long bars and four generators for the short bars, namely, a total of six, instead of seven which would be required if the equalisers were not used.

The method of connecting up the balancers required in connection with this system should be noted. The connections are so arranged that either of the balancing generators can be switched on to either of the positive or negative bars connected to the long or short feeders.

With the plugs arranged as shown in fig. 172, the left-hand generator in the diagram is connected between the long negative and neutral bars, whereas the right-hand generator is connected between the long positive and neutral bars. If the change-over plugs were inserted in the top holes instead of the second holes, the left-hand generator would then become the positive and the right-hand one the negative generator. Two such panels provide for the connection of one pair of balancers to the long bars, and another pair to the short bars, or all four balancers may be connected to one set of bars.

It will appear, on referring to fig. 172, that the insertion of one change-over plug in the top hole Y, when a second plug is in the middle hole X, will cause a short circuit across this generator. To provide against this a guard slab is arranged to slide over the change-over plug holes in such a manner that it is impossible to insert a second pair of plugs before withdrawing the first pair.

When the guard is in the position in which it is shown in fig. 173, the plugs may be inserted in the middle holes. To insert plugs in the top or bottom holes, the guard slab must be shifted to the left or to the right, and this cannot be done until both the plugs have been withdrawn from the middle holes.

The batteries, of which there are two, are connected up as shown in fig. 174. Each battery consists of 140 cells. The batteries are joined in series, one (H) being connected between the positive bars and the third wire, and the other (J) between the latter and the negative bars. Connections from thirty regulating cells $H^1$ $J^1$, on the extreme end of each battery, are brought to four regulating switches $I^1$ $I^2$ $I^3$ $I^4$ (two on each pole). These switches are fixed in a glass house in the battery-room, which is some distance away from the main switchboard. They are nevertheless controlled from the switch gallery. Each regulating switch is mechani-

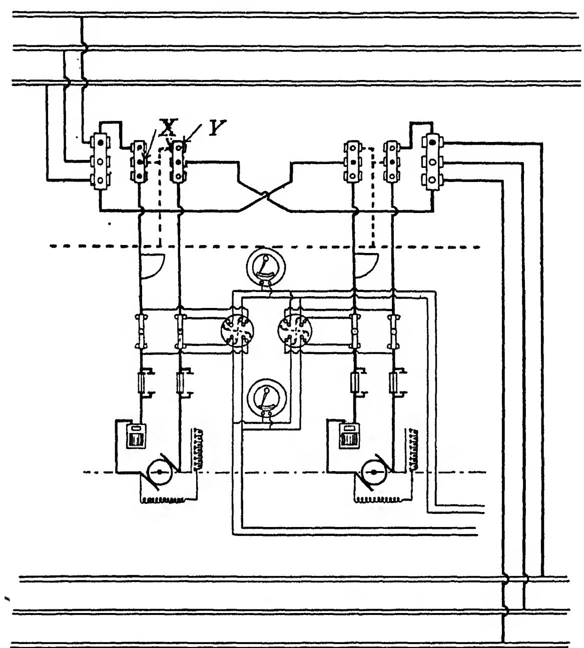



Fig. 172.—Connections of balancer panels (Edinburgh).

cally connected to a hand-wheel (see fig. 153) on the switch gallery by means of a steel wire maintained in constant tension, and run through an iron pipe to prevent sagging. The construction is such that a complete turn of the controlling handle just cuts one cell in or out. An indicator on the wheel shows the number of cells in circuit.

The movable contacts of the regulating switches are provided with pilot contacts; these are connected to the main contacts through resistances, to prevent the cells being short circuited when moving from one contact to the next. If by accident the movable contact should be left in an intermediate position, the charge or discharge current will

pass through this resistance. To obviate trouble from this cause a relay is shunted across the resistance, and this, when current is passing through the resistance, closes a local circuit and rings a bell on the switch gallery.

The object of the two regulating switches on each pole is to enable the battery to be simultaneously connected across two distinct systems requiring different pressures and independent regulation. Thus in fig. 174, 138 cells are connected across the long positive bar and the third wire, and 138 cells between the latter and the long negative bar; whereas only 113 cells are connected on each side between the short

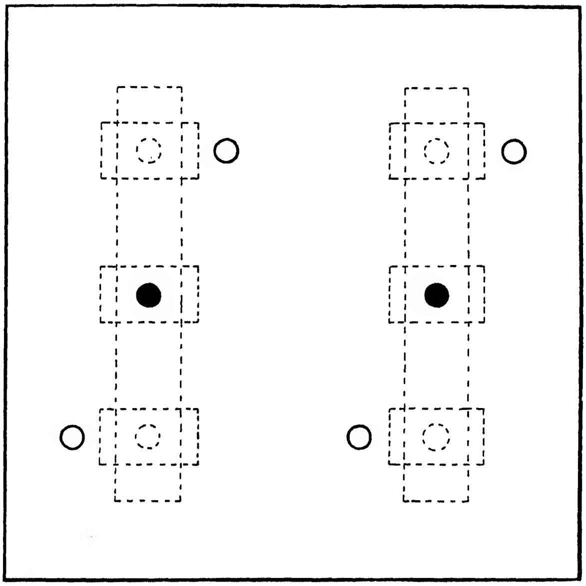


FIG. 173.—Guard slate for plugs.

bars and third wire. It will be evident that all cells up to 113 are being discharged at the rate of the current supplied to the short bars, plus the current supplied to the long bars; whereas cells 113 to 138 are being discharged at the rate of the supply to the long bars only.

The ammeters $D^8$ $D^9$ (fig. 174) between the regulating switches and the positive and negative 'bus bars show the rate of discharge or charge to or from the long or short bars, and the ammeters $D^{10}$ $D^{11}$ between the battery and the third wire show the total rate of charge or discharge.

Separate cables $Q^1$ $Q^2$ are run from the third wire side of each battery to the switchboard, so that the batteries can be entirely disconnected from each other.

To charge the batteries, boosters $T^1$ $T^2$ are inserted in series with the

connection to the third wire. $T^1$ or $T^2$ is plugged on, and its two switches closed, thus connecting it across the main disconnecting switch $S^9$ or $S^{10}$ on the third wire. The motor $M^1$ or $M^2$ driving this booster is then run up to speed, and the main switch $S^9$ or $S^{10}$ is opened, the unexcited armature winding thus becoming part of the battery circuit; by exciting the field of the generator, and by varying the resistance in circuit with it, any desired pressure may be added to the 'bus bar voltage.

Either of the two boosters provided may, by means of the plug connectors, be connected in series with either battery. If plugged as shown in fig. 174, the right-hand booster in the diagram is connected in series with the positive, and the left-hand booster with the negative battery. If the plugs were inserted in the top holes, the above arrangement would be reversed. By plugging the boosters on to the bottom contacts they may be used as balancing equalisers.

### Hull (High-Tension Direct Current).

In districts where the area of supply is very scattered, and there is a considerable demand for power, some engineers advocate the use of a high-tension direct current, constant pressure system. This system is in successful operation at Hull, Oxford, and a few other towns in this country. Current is generated at a pressure of from 2000 to 3000 volts, and is transmitted to sub-stations at this pressure, and there transformed down by rotary continuous current convertors to a pressure of 400 volts, and distributed as such on the three-wire system.

The general system of control is illustrated diagrammatically in fig. 175. Each generator D is connected to the main 'bus bars through a double-pole return current circuit-breaker E. From these 'bus bars a number of concentric feeders are run to a corresponding number of transformers grouped in sub-stations at different points of the area of supply, there usually being four or five transformers in each sub-station. Each feeder is connected directly on to the terminals of its transformer; that is to say, there are no high-tension circuit-breakers in the sub-stations. In the generating station a feeder panel is provided for each feeder or transformer. This panel is equipped with a voltmeter F for indicating through pilot wires the pressure at the feeding point, an ammeter G, a double-pole automatic excess current circuit-breaker H, and a regulating switch *a b c*. The regulating switch is divided into two distinct halves. One half, *ab*, cuts in or out a fine wire resistance used for starting purposes only; whereas the other half, *bc*, controls a much heavier resistance, a portion of which may always be left in circuit for obtaining an accurate regulation of pressure at the feeding point when running under load. There are also two pilot-wire switches, one of which, J, is used for connecting the voltmeter across

the distributing system, or across the low-tension terminals of the transformer, before the latter is connected to the distributing system, and the other, K, for controlling through the pilot wires the low-tension switch S in the sub-station.

To start up a transformer the voltmeter switch J is placed in contact

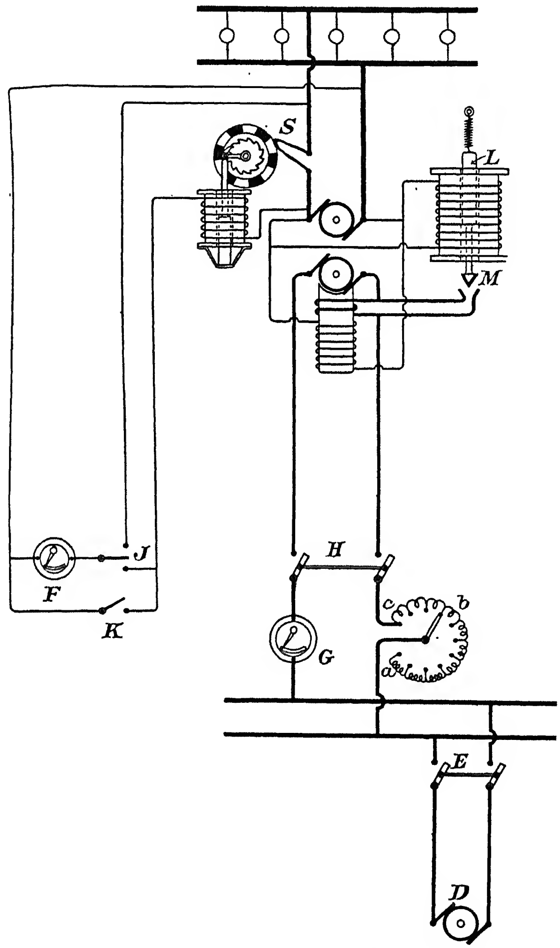



Fig. 175.—General system of control (Hull).

with the upper stud, to ascertain the pressure across the low-tension 'bus bars in the sub-station, and this pressure is noted. The switch is then changed over to the lower contact. This will now show the pressure across the low-tension terminals of the transformer. The whole of the starting and regulating resistance is inserted in series with the feeder by means of the regulating switch, and the double-pole circuit-breaker H is

then closed; this completes the circuit through the primary of the transformer. The starting resistance is then slowly cut out. An increase of the current causes the armature of the transformer to rotate as an ordinary series motor. As the back E.M.F. of the motor increases with the speed, the starting resistance is further cut out. At first the field magnets of the transformer are excited by the series winding only, but as the armature gains speed the field due to the series is supplemented by a current in the shunt winding generated by the secondary winding on the rotating armature. When the E.M.F. across the secondary terminals of the transformer has risen to about 75 per cent. of its normal pressure, the plunger L of the automatic cutout M is drawn down, and the series winding of the transformer is thus short-circuited; the transformer then continues to run as a shunt wound motor. The starting resistance is then further reduced until the voltmeter indicates a pressure across the secondary terminals of the transformer identical with the pressure previously noted across the distributing 'bus bars. When this balance of pressure is obtained the switch S is closed between the secondary terminals of the transformer and the low-tension 'bus bars. The starting resistance is finally further cut out until the transformer is taking its proper share of the load, as indicated by the ammeter G.

The switch S is closed from the generating station by means of the pilot switch K. It will be seen from the diagram that by closing the switch K a circuit is completed through the operating coil of the switch S. An illustration of this long distance switch is shown in fig. 176. A very powerful iron-clad coil C lifts a heavily weighted armature when its circuit is closed. This armature carries a light metal framework, to which are fixed two pawls P and $P^1$. These pawls engage in a ratchet tooth wheel T. When the armature and framework are drawn up by the attraction of the magnet, the pawl P engages in one tooth of the ratchet wheel, and rotates this in a clockwise direction through an angle of 45 degrees. Upon the circuit through the magnet being broken the armature falls by gravity, and the pawl $P^1$ engages in another tooth of the ratchet wheel, and rotates this, also in a clockwise direction, through a further angle of 45 degrees. The ratchet wheel may thus be constantly rotated in one direction by repeatedly making and breaking the circuit of the operating magnet.

An arm D, carrying rollers R and $R^1$, is rigidly fixed to the ratchet wheel, and when this is rotated through an angle of 45 degrees from the position in which it is shown the roller $R^1$ comes in contact with and closes the arm E, carrying the short-circuiting contacts. The second movement of the ratchet wheel carries $R^1$ away from E, and would allow the spring S to pull the contact arm out of the closed position, but this movement is prevented by the catch G. The third movement, however, causes the roller R to

come in contact with and to lift the catch G, and thus allows the contact arm to be pulled out of the closed position by the spring S. The catch should also be released by the armature of the magnet M, in the event of a heavy current flowing back from the secondary 'bus bars into the low-tension winding of the transformer. This cutout magnet is wound with two windings, one of these windings being in series with the connection between the transformer and the 'bus bars, and the other being connected across the 'bus bars. So long as the generator is supplying current to the

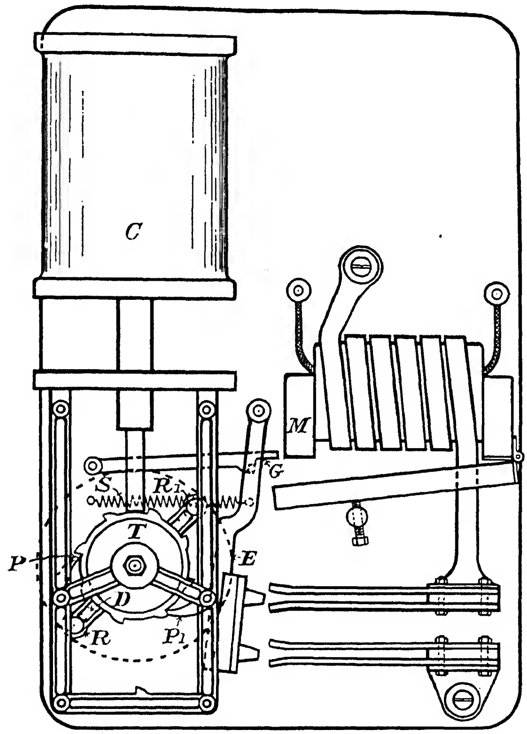



FIG. 176.—Long distance switch.

'bus bars these two windings neutralise each other, and there is consequently little or no magnetic pull upon the armature. If, however, current should return from the 'bus bars to the generator, the two windings will assist each other to magnetise the core of the magnet, and the armature will be attracted up, and will, with a smart blow, trip the catch holding the switch in its closed position. This long distance switch is constructed on such thoroughly mechanical lines that there is perhaps little chance of its failing. Should it do so, however, the attendant at the generating station will be able to detect it by noticing the

behaviour of the ammeter and voltmeter connected to this particular feeder, and will then send a man to this sub-station to operate the switch by hand.

The low-tension current is distributed on the three-wire system. Some of the transformers are connected directly across the 400-volt wires, but other transformers are wound to give 200 volts only, and are connected between the outer and middle wires of the system. The latter are used as balancing transformers.

### Hastings (Single-phase Alternating Current System).

In many towns the area of supply is of such a scattered nature that distribution cannot be effected economically even by aid of the three-wire system, at pressures of less than 500 volts, and the demand for motors is, and always will be, so extremely limited that the installation of a H.T. continuous current system or of a polyphase system is not justifiable. Hastings and St Leonards, being purely residential districts, are typical examples of such an area of supply. It is generally admitted that for distributing electricity to such a district the single-phase alternating current system is most eminently suited.

Current is generated at Hastings at a pressure of 2200 volts, and is fed to convenient centres throughout the area of supply, and there transformed down to the pressure required. Until a few years ago the pressure was reduced to 100 volts by a large number of transformers placed on consumers' premises or in transformer chambers under the streets. This was, however, far from satisfactory. Quite apart from the risks of fire, etc., the arrangement was very inefficient, as the magnetising current losses in so many transformers were very heavy. The controlling arrangements were also very unsatisfactory, as the transformer switches and fuses were all placed in the transformer cases, and consequently when a transformer failed it often set up an arc which short-circuited the switches and fuses; and as no other means was provided for isolating the fault, a complete shut-down was often rendered necessary.

In view of the difficulties referred to above, it was decided to group the transformers in a few properly equipped sub-stations. To limit the number of sub-stations, the supply to consumers' lamps was increased from 100 to 200 volts, and triple concentric distributors were laid, to permit of distribution on the three-wire system with 400 volts across the outer conductors. Thus it was found possible to economically arrange the sub-stations from half a mile to three-quarters of a mile apart.

At the time these alterations were made it was the common practice

to place sub-stations under ground, the usual means of entrance being through a trap door. The author was strongly opposed to this practice, and made a great effort to keep all the sub-stations at Hastings above ground, so that they could be entered for inspection by merely unlocking an ordinary door. Some considerable difficulty was experienced in getting all the necessary sites in the centres required, but they were ultimately secured, and the result has more than justified the effort.

Sufficient attention has not always been paid to the arrangement of conductors in sub-stations. These are often bunched together without any attempt to keep them in any sort of order. As a result, when a fault occurs, a considerable amount of time is wasted in tracing out the connections. The leads to and from the feeders, distributors, transformers, and controlling apparatus should be arranged in such a manner that the purpose of each can be seen at a glance.

Figs. 177 and 178 show the H.T. and L.T. sides of one of the Hastings sub-stations, and fig. 179 is a diagram of connections. All the H.T. cables are encased in steel tubes cleated to the wall, so as to be clearly diagrammatical. The tubes containing the inner wires are painted red, and the outer or earthed wires black. The H.T. 'bus bars are fed by two distinct feeders connected in parallel through a discriminating choking coil (see Chapter V.).

The transformer fuses are mounted on two panels fixed to the wall, a separate panel being provided for each half of the station. The failure of a fuse, causing an arc, on one panel is therefore not liable to affect the other panel. A hinged guard slate, which normally covers the fuse contacts and H.T. 'bus bar, may, on removing the fuse plugs, be lifted for examining the contacts.

The transformers are arranged in pairs, the secondaries being wound for 200 volts, and coupled in series to give 400 volts across the outer conductors of the three-wire system. A single conductor is run from the connection between each pair of transformers to the neutral 'bus bar to which the outer conductor of each triple concentric distributor is directly connected. The outer terminals of each pair of transformers are connected to the L.T. 'bus bars through a concentric cable, and a discriminating cutout is inserted in series with each conductor. The advantage of using a concentric cable for this purpose is that it entirely prevents any risk of a mistake being made in making or altering the connections—such, for instance, as an inner lead being connected to an outer 'bus bar.

Ammeters, a three-wire wattmeter, and a double pole switch are inserted in the L.T. 'bus bars between the transformers and the distributors. A comparison of these sub-station wattmeters with the generating station wattmeters and with the sum of the consumers' meters shows the difference between the secondary units distributed and the primary units generated,

and between the former and the units sold. The main switch enables the sub-station to be disconnected from the distributing network on the secondary side without opening all the transformer switches.

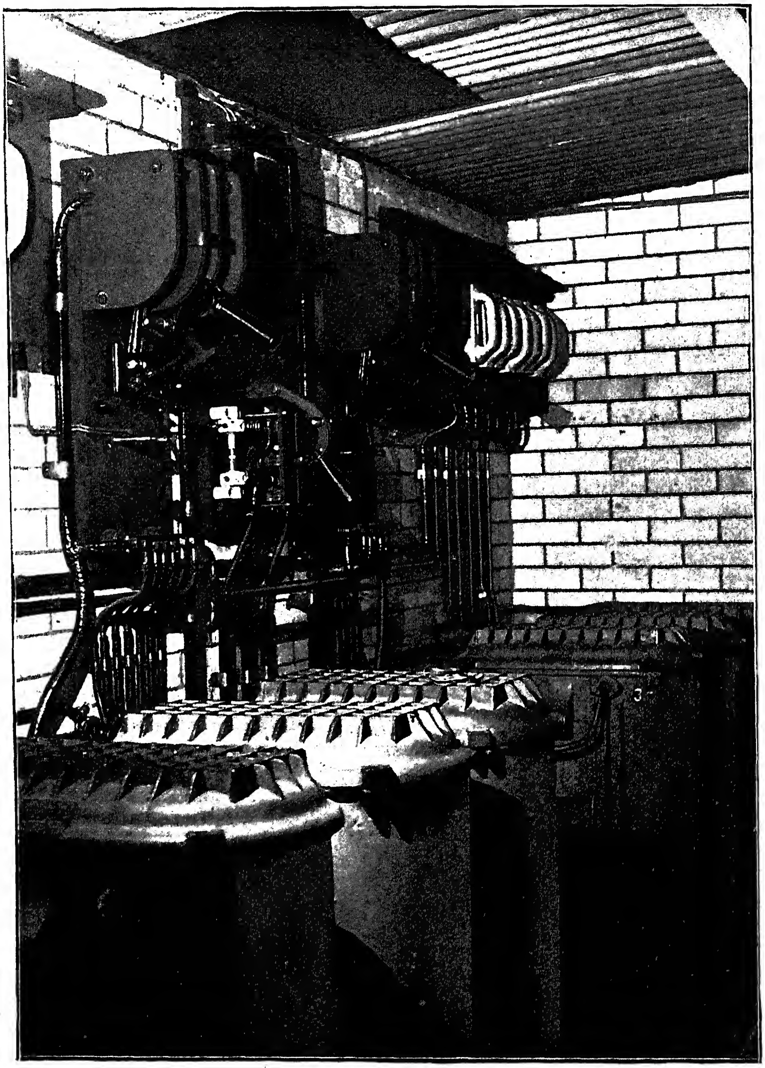


FIG. 177.—High-tension side, Hastings sub-station.

The distributors are divided into two distinct networks, each large network consisting of a group of small networks interconnected through fuses only at the sub-stations. Thus in fig. 180 the small network C is only connected to adjoining networks at the sub-stations A and B.

This arrangement has many advantages. In the first place, should a low-tension short circuit occur on any distributor, the fuses at each end of the small network are blown, and the fault is isolated from the rest of

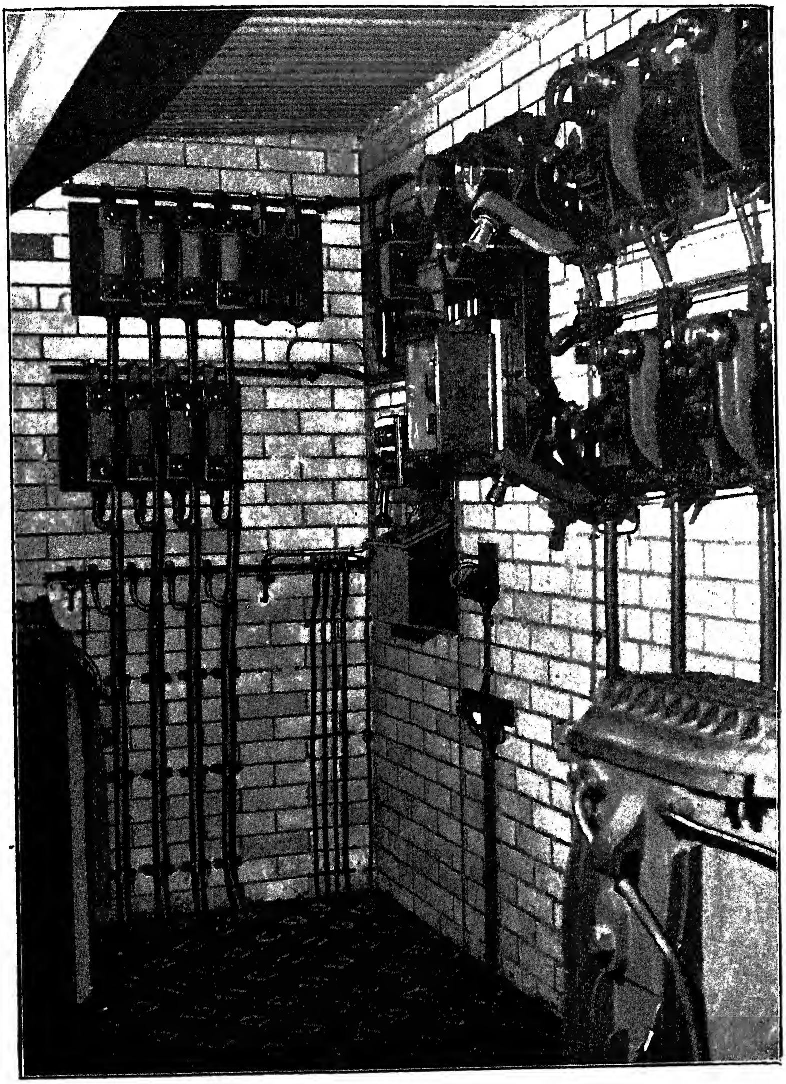


FIG. 178.—Low-tension side, Hastings sub-station.

the system. This, in addition to limiting the effect of the failure, greatly simplifies the work of localising the fault. It will be seen that each small network is connected, either directly or indirectly, to a sub-station adjoining the generating station. This one sub-station may be supplied

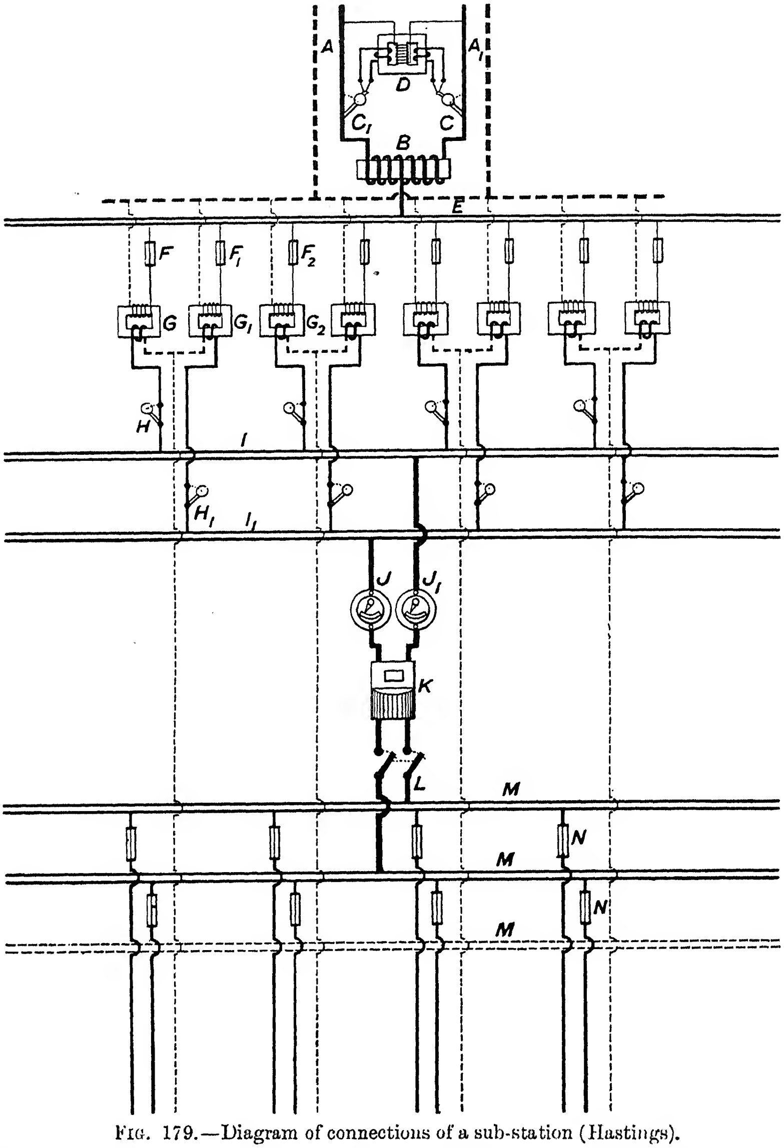



FIG. 179.—Diagram of connections of a sub-station (Hastings).

A and A¹, high-tension feeders supplying sub-station; B, discriminating choking coil; C and C¹, switches for disconnecting either feeder; D, discriminating transformer for operating switches C and C¹; E, high-tension 'bus bars; F, F¹, F², etc., high-tension fuses; G, G¹, G², etc., 20 kilo-watt transformers; H and H¹, low-tension discriminating cutouts; I and I¹, low-tension 'bus bars; J and J¹, main ammeters; K, main three-way wattmeter; L, double pole main switch, for disconnecting secondaries of transformers from distributing 'bus bars; M, M, and M, distributing 'bus bars; N and N, fuses on distributors.

from a small day load plant at the generating station, the current from

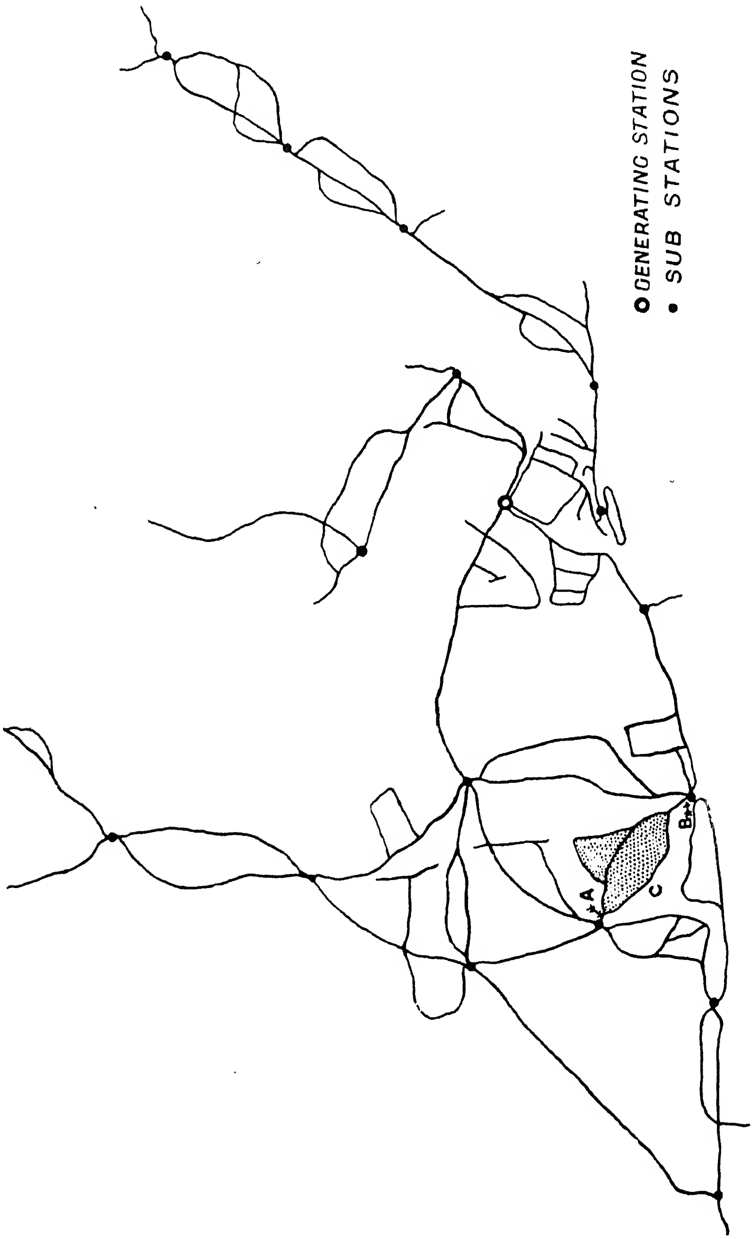



Fig. 180.—Diagram of L.T. distributors (Hastings).

the plant being conveyed directly to the transformers without going through the main switchboard. This enables the whole of the high-

tension system to be shut down during the hours of light load, thus entirely preventing the usual heavy losses in magnetising current and cable-charging current; and, what is, perhaps, of even greater importance, the necessity of working on live high-tension connectors is entirely avoided. It may be thought that the drop of pressure when feeding through the distributors alone would be prohibitive. As a matter of fact, the day load during the long summer days is less than 10 per cent. of the maximum night load, and consequently the distributors will transmit the current ten times the distance with the same drop of pressure.

To switch off the H.T. system, the main L.T. switches in each sub-station are first opened, thus disconnecting the secondaries of the transformers from the L.T. network. The sub-station at the works is then changed over to the day load plant, and the whole of the H.T. system is shut down. To change back again, the H.T. cables and transformers are run up to full pressure and the L.T. sub-station switches are closed. These switches may be closed through pilot wires run from each sub-station to the generating station. A pilot wire board at the works is equipped with small switches for operating the main sub-station switches, with lamps on each pilot wire which are extinguished should a transformer break down and cause its discriminating cutout to operate, and with a static voltmeter by means of which the distributing pressure at any sub-station may be ascertained.

Each sub-station is connected by a private telephone line to the works and to other sub-stations.

## CHAPTER X.

### LONG DISTANCE TRANSMISSION.

Determination of line pressure—The use of copper, aluminium, or steel for overhead conductors—Wooden or steel posts for transmission lines—Insulators, glass and porcelain—Leading in wires—Cable charging devices—Pressure rises due to open air arcs—Lightning arrestors: 'Thomson,' 'Siemens,' 'Wurtz,' and 'Stanley'—Arrangement of choking coils and lightning arrestors—Requirements that should be fulfilled by lightning arrestors—Earthed guard wire for lightning protection—Regulation of pressure, 'Cowan-Still' regulating transformer—'Paderno' three-phase transmission scheme—'Thury's' E.H.T. constant current system; simplicity of controlling arrangements; regulation of motors; excess potential cutout—Valtellina Electric Railway; motors coupled in cascade.

If there is one field, more than any other, in which electricity stands unrivalled, it is in the transmission of energy over long distances. The commercial transmission of large powers over lines from 100 to 300 miles in length is now a matter of daily occurrence, both in Europe and America, particularly on the West Pacific coast; one of the most notable instances being the Standard Bay Counties line, carried out by the Stanley Electric Manufacturing Co., under the supervision of Dr Perrine.

In this country the demand for such schemes has not, so far, arisen, and is not likely ever to do so; it is, in fact, probable that the use of long distance transmission lines will here be confined to electric railway work, though lines of moderate length will doubtless be largely used by some of the power distributing companies.

Long distance transmission, to be a commercial success, entails the use of overhead wires, and the working at very high pressures. Both these factors introduce problems in connection with the controlling arrangements that do not arise, at least to the same extent, when working underground cables at moderate pressures.

**Determination of Line Pressure.**—One of the first questions to be determined upon is the line pressure. A rough and ready rule suggested by Mr C. F. Scott, for determining the most economical pressure, is that the pressure in thousands of volts should equal one-third of the number of miles over which energy is to be transmitted.

**Conductors.**—Overhead conductors are usually of copper, though aluminium has been employed in several transmission schemes. The latter has a higher tensile strength than copper, compared to its specific gravity,

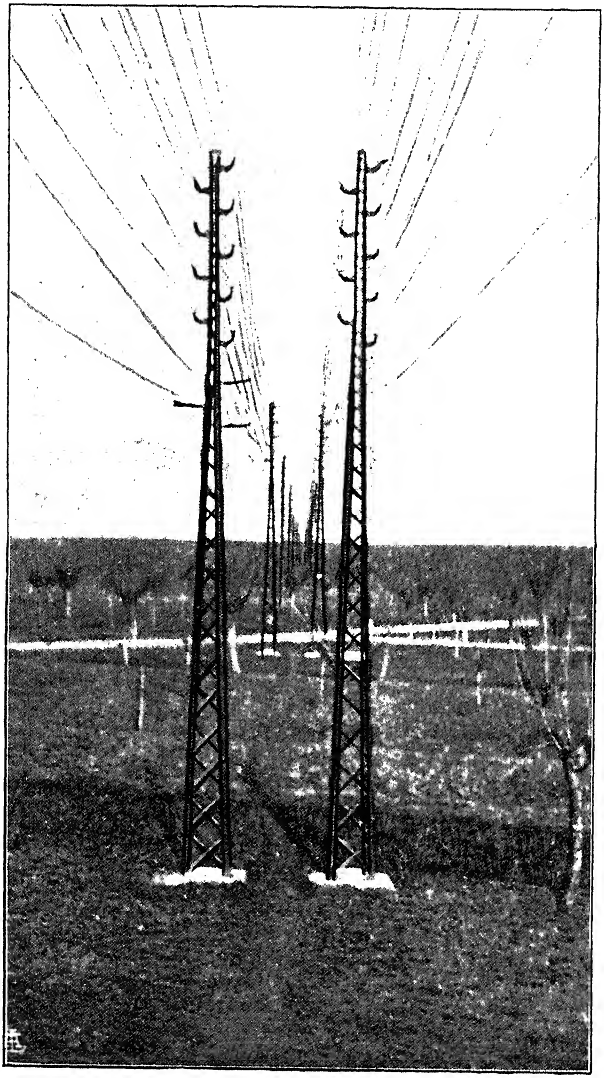


FIG. 181.—Steel post transmission line.

but its conductivity per square inch section is lower, and consequently the surface exposed to wind pressure is considerably greater.

Dr Perrine in his book on *Conductors for Electrical Distribution* gives the

following relative values of copper and aluminium for a given length and resistance :—

| | Copper. Per cent. | Aluminium. Per cent. |
|---|---|---|
| Diameter | 100 | 127 |
| Area | 100 | 164 |
| Tensile strength | 100 | 63 |
| Specific gravity | 100 | 50 |

For crossing large rivers where there are no bridges cast steel wire is used, on account of its high tensile strength. In these cases the high resistance of this wire is not an important factor, considering the short

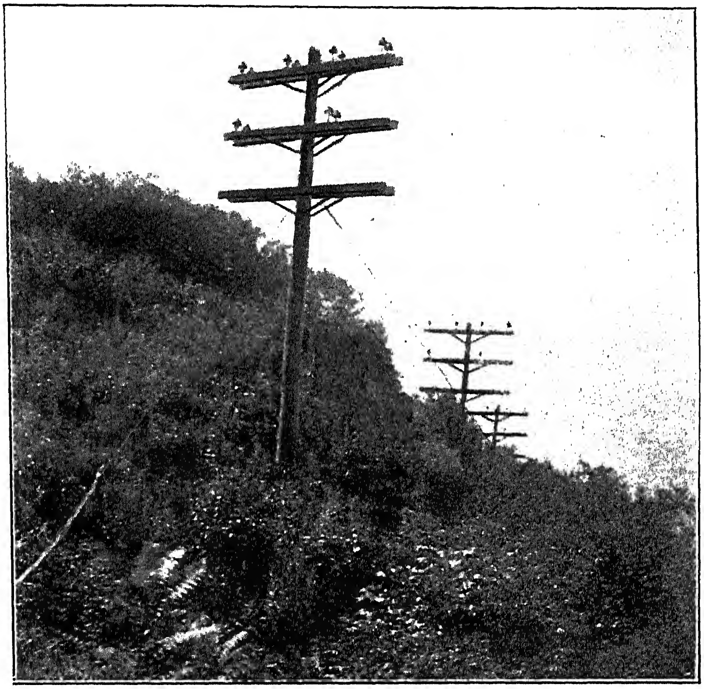


FIG. 182.—Wooden post transmission line.

lengths employed. Such spans have been erected in Egypt and India exceeding a mile in length.

**Posts.**—The posts for supporting the overhead lines may be wooden or steel structures. Both are largely used. Fig. 181, reproduced from a photograph of the transmission line between Paderno and Milan, is an example of the latter construction. The two lines of posts carry between them six parallel three-phase lines—eighteen 9-mm. wires in all. The distance between the supports is about 200 feet, and the total length of line is about 20 miles, the pressure of the supply being 13,500 volts.

Fig. 182 shows the wooden posts of the Hudson River power

transmission line. These are of chestnut, and are from 30 to 60 feet high. The 35-foot posts are about $14\frac{1}{2}$ inches diameter at the ground level, and about $7\frac{1}{2}$ inches at the top. They are spaced from 50 to 100 feet apart.

The author was informed by an engineer who had carried out some of the large transmission schemes in the States that the cost of a steel post line is little, if any, greater than that of a wooden post line.

**Insulators.**—Considerable difficulty has been experienced in getting an insulator to withstand these high electrical strains, and to be at the same time of sufficient mechanical strength. Various materials have been experimented upon, but glass or porcelain is now almost universally used.

Fig. 183.—Glass insulator.

Ordinary brown pottery is in itself extremely porous, and can only be kept dry by a heavy external glaze. This glaze is liable to be ground off by the continual swaying of the heavy wires. Glass is very largely used in the States, particularly for pressures below 20,000 volts. A peculiar advantage arising from the use of glass is that, owing to its transparency, it possesses no dark recesses. It appears that considerable trouble has been caused by insects congregating and building their nests under the petticoats of porcelain insulators, the dark recesses of which appear to be particularly attractive to them. Fig. 183 shows the usual construction of these glass insulators.

For the higher pressure lines working up to 50,000 volts a hard paste porcelain of great mechanical strength is generally used. These insulators are often manufactured in two or more parts and then cemented together.

This method of construction ensures more uniform insulation, and reduces the risk of breakdown due to defective manufacture.

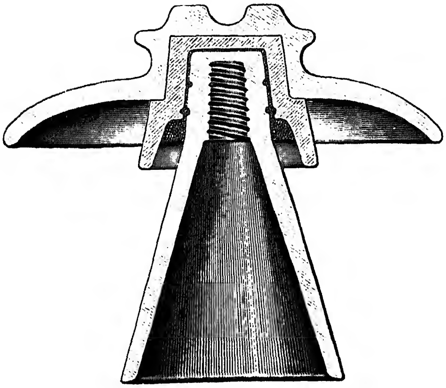


FIG. 184.—Locke porcelain insulator.

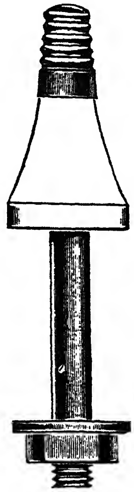


FIG. 184A.—Pin for Locke insulator.

An insulator largely used in the States is the Locke insulator,

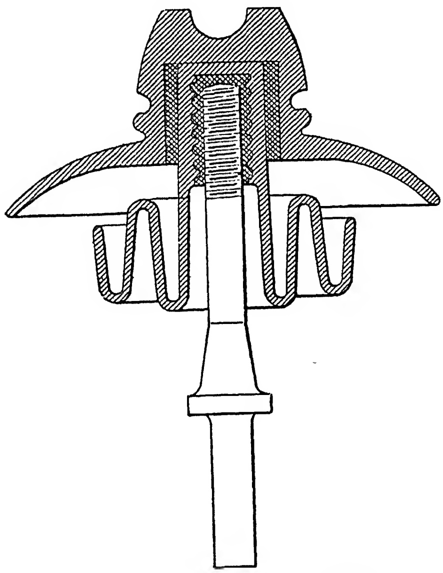


FIG. 185.—Cloche Mehun insulator.

illustrated in fig. 184. This insulator is constructed of three distinct parts; the top and intermediate pieces are fused together, and the centre

piece is cemented inside the others. The complete insulator may be mounted on a wooden pin or on a steel pin capped with porcelain, as illustrated in fig. 184A.

A section of the Cloche Mehun insulator is illustrated in fig. 185; this insulator has been used for a large number of transmission lines on the Continent.

**Leading in Wires.**—The leading of overhead wires into buildings

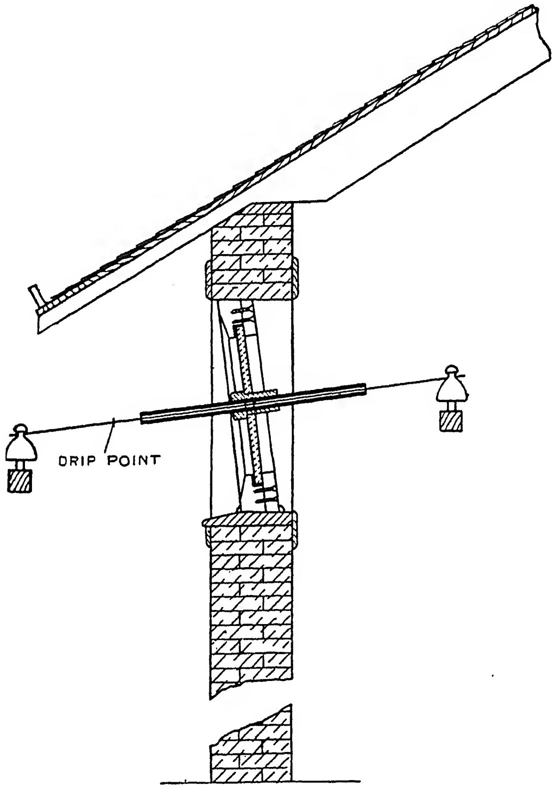



FIG. 186.—Method of leading in H.T. transmission line.

is a subject that has received a considerable amount of attention. The matter was discussed at some length at a recent meeting of the American Institution of Electrical Engineers, and a number of systems in use were then described. The method that appeared to meet with the most general approval was that described by the author of the paper, and illustrated in fig. 186. This consists of a long insulating tube of small internal diameter and of considerable thickness, placed over the wire and supported in a slab of insulating material set in the wall of the building, the

whole being protected from driving rain by an extension of the roof. It is stated that this method has been successfully used for 50,000-volt lines.

In some cases the wires are brought in vertically through the roof. Fig. 187 is a section of the roof insulator in use at the Canyon Ferry plant of the Missouri River Power Co.

**Cable charging Devices.**—Special precautions have to be taken in connection with all long distance transmission lines to guard against a breakdown of insulation due to abnormal rises of pressure. Mr R. H. Thomas, in his paper on Static Strains in high-tension circuits, shows that when a line is suddenly charged from live 'bus bars, a momentary voltage rise may be produced of approximately double the normal voltage, and under some circumstances a great deal more.

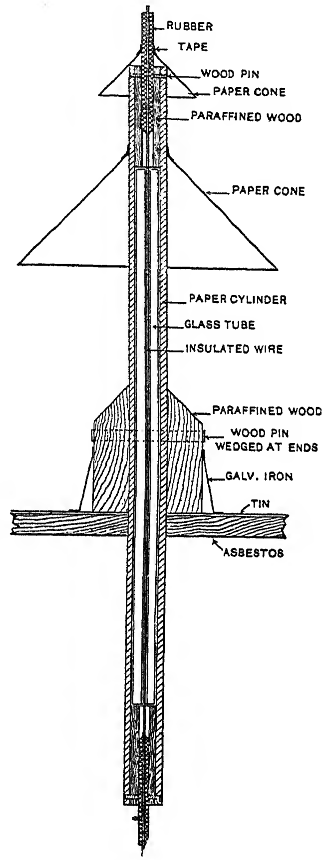



Fig. 187.—Method of leading in H.T. wires through roof.

To prevent pressure rises from this cause, Messrs Ferranti have introduced the cable charging device illustrated in fig. 188. It consists of a metal containing vessel A supported in a cast iron case B, on and by insulators $C^1$ $C^2$ $C^3$. In the containing vessel are rigidly fixed two porcelain tubes $D^1$ $D^2$, these tubes being about 5 feet long by 3 inches internal diameter. Each tube contains an ebonised iron rod E, carried at its upper extremity by an insulator D. At the lower end of this rod is a piston F, upon which is fixed a metal cap G. This cap is electrically connected to the terminal H by a spiral tape conductor I. The piston F fits into a well at the bottom of the containing vessel, which is filled with mercury. A gauge glass J enables the height of the water to be seen through a glass window in the outer case. The height of this water is normally kept about 3 feet above the bottom of the containing vessel, and the total upward travel of the rods is 2 feet 10 inches. The apparatus illustrated is intended for use in connection with a two-phase system, one tank being provided for each phase. The ebonised rods are carried at the extremities of a connecting cross-head. The weights K tend to lift the cross-head, but this is

prevented when the rods are in the lowest position by a catch controlled by an electro-magnet L.

The method in which this charging gear is inserted in circuit with the feeders is shown in fig. 189. The connections are shown for a single-phase system only. To charge a feeder the catch is released, thus allowing the balance weights to lift the cross-head, and so increase the length of the column of water to its maximum. The feeder switch is set at half-cock, thereby connecting the feeder to a small auxiliary 'bus bar corresponding to the synchroniser bar in the Ferranti standard generator switchgear.

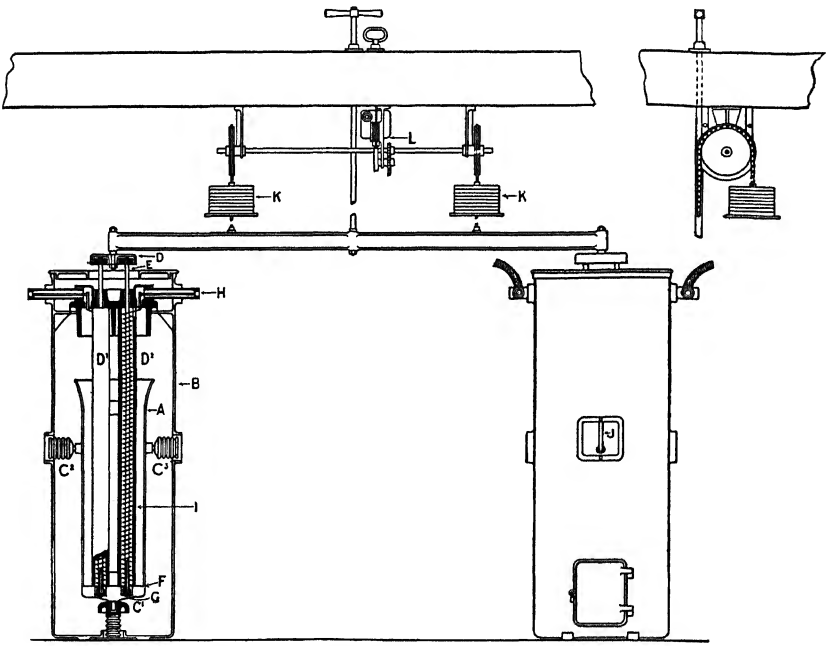



FIG. 188.—Ferranti cable charging apparatus.

This bar is connected to one terminal of the cable charging device. The other terminal is connected to the main 'bus bar through a fuse and switch on a special feeder charging panel. The water resistance in series with the feeder is then gradually reduced by pushing down the cross-head to its extreme limit of travel. This is done by a length of rod terminating in a handle above the switchboard gallery. When all the resistance has been cut out the catch comes into operation and holds the cross-head down; the feeder switch is then finally closed. A hand release to the catch is provided to enable the apparatus to be used for charging another cable in a similar manner. To discharge a feeder the rods are pushed down to their lowest position (if they have not previously been left thus), and the

feeder switch is pulled out on to the second contact. In this position the magnetic release trips the catch, and thus allows the weight to descend and gradually increase the length of the column of water. The operation is finally completed by opening the oil break switches on the feeder charging panel. A plug switch is provided for isolating purposes only.

Messrs Cowans have supplied their standard regulating transformers (see figs. 199A and 199B) for cable charging purposes. These are constructed to gradually increase the pressure from zero to the full working pressure required.

**Pressure Rises due to Open Air Arcs.**—Enormous rises of pressure are liable to result from suddenly interrupting a heavy current in open air. Mr Steinmetz found that the surge E.M.F. of an overhead circuit may be 100 times greater than the E.M.F. of the generator.

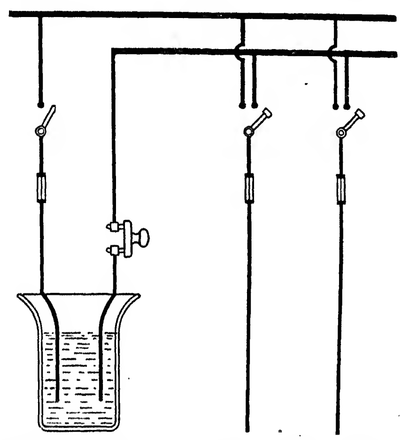


FIG. 189.—Diagram showing connections of cable charging apparatus.

Dr Kennelly points out, in an article in the *Electrical World*, Nov. 23, 1901, that if a circuit while carrying an alternating current is broken, the magnitude of the succeeding surge will depend upon the value of the current at the instant of rupture.

If the alternating current happens to be interrupted just at the zero point of the wave, the resulting surge will be negligibly small. If, on the contrary, the alternating current wave of the circuit is at its crest or maximum, then the surge due to its interruption will be the same as though a continuous current of that full magnitude had been interrupted. Experience has shown that an air break switch can never be relied upon to break under the same conditions two or three times following. This is attributed to the fact that the rupture is liable to occur at any point of the current curve. It appears, on the other hand, to be generally admitted that an oil break switch always behaves consistently, and it has been

suggested that the reason for this is that the oil closes in and extinguishes the arc just at the moment when the current wave is passing through zero. In consequence of this valuable feature, oil break switches are now being almost universally used for controlling H.T. alternating current transmission circuits.

**Protection against Lightning.**—The insulation of overhead transmission lines and apparatus connected therewith is often ruptured by abnormal rises of pressure due to atmospheric disturbances. To guard against breakdowns from this cause, overhead systems are invariably equipped with some form of lightning arrestor, constructed to allow the

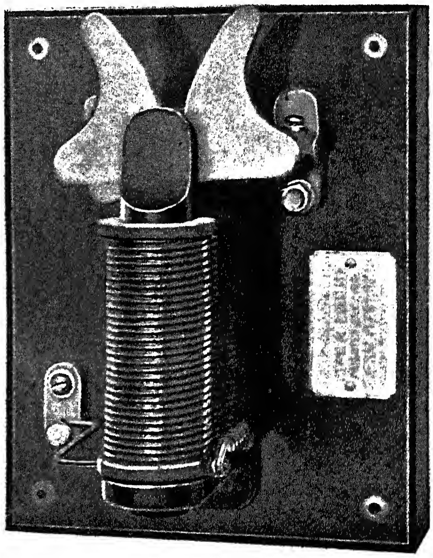


Fig. 190.—Thomson lightning arrestor.

static discharge to pass to earth without breaking down the insulation of the line at other points, and to prevent the generator current from following the static discharge.

One of the earliest devices introduced for this purpose was the Thomson arrestor, illustrated in fig. 190. This arrestor is still largely used.

Two horn-shaped pieces of metal, supported on an insulating base, are separated from each other by a small air gap. One of these horns is connected to the line to be protected, and the other is earthed. The discharge points are placed between the poles of an electro-magnet, in such a position as to be in a strong magnetic field when the magnets are energised. Should a heavy current follow the static discharge, it flows

round the coils of the magnet, and, creating a powerful field, blows the arc to the tips of the horns and thus interrupts the flow of current.

A modification of the above is the Siemens horn break arrestor, shown in fig. 191. This is based on the principle of the horn break switch illustrated and described in Chapter III.

The Wurtz arrestor, illustrated in fig. 192, consists of a number of metal cylinders (usually seven) arranged side by side and carried between two porcelain blocks. These blocks are constructed to maintain a small and even spacing between the metal cylinders. Each unit constitutes, therefore, a number of minute spark gaps in series. In the event of an abnormal rise of pressure occurring, the spark gaps are easily bridged by the static discharge. As this immediately relieves the pressure, the arc is ruptured, partly due to the cooling effect of the large number of cylinders, and also due to the fact that these cylinders are usually constructed of a combination of metals that produce, when volatilised, a non-conducting vapour which immediately extinguishes the arc. For pressures over 2000 volts a number of the units described above are usually connected in series, an additional unit being generally allowed for each 2000 volts.

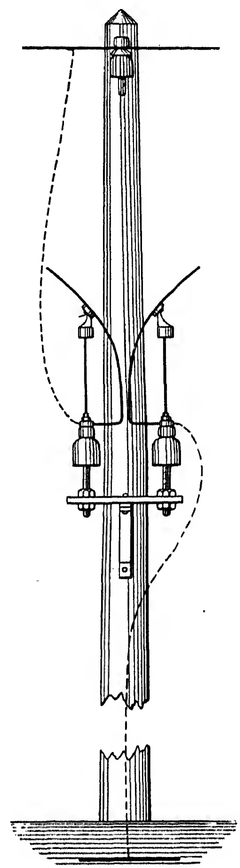


FIG. 191.—Siemens horn lightning arrestor.

Fig. 193 is a cross section of the Stanley Electric Manufacturing Co.'s standard arrestor, and fig. 194 shows the unassembled parts of one of these arrestors. Each of these units consists of a nest of concentric tubes, with diverging ends, held in relative position by perforated porcelain caps at top and bottom. These caps are in turn securely fastened to an insulating support of marble or porcelain by an external hoop. The innermost cylinder is connected to the line to be protected and the outer to earth. The grooves in the porcelain caps are so spaced as to definitely maintain all spark gaps one-sixteenth of an inch wide.

An abnormal rise of pressure on the line causes the static discharge to jump the gaps in the narrower portion of the arrestor, and so to pass to earth through the outer cylinder. Should the generator current follow the static discharge, a current of air is established in the arrestor, causing the arc to rise to the upper part of the arrestor, where the width of the

gaps is so greatly increased as to ensure the arc being extinguished. It will be obvious that this concentric construction provides a very large discharging surface.

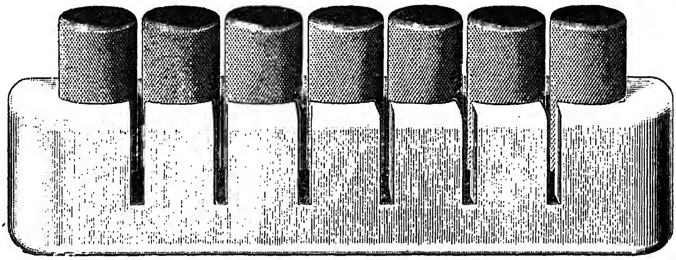


FIG. 192.—Wurtz lightning arrestor.

Fig. 195 shows two of the units described above connected in parallel and mounted on a porcelain base.

In addition to providing an easy path for the discharge of static currents to earth, it is necessary to take some steps to prevent the

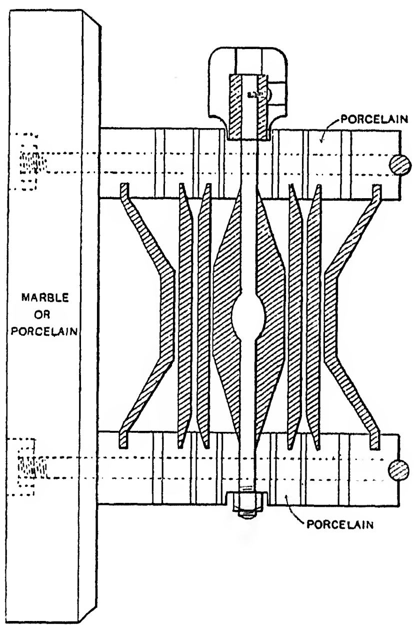



FIG. 193.—Section of Stanley lightning arrestor.

abnormal rise of pressure getting into the apparatus connected to the line. For this purpose it is usual to insert a choking coil between the connection to the lightning arrestor and the generators or transformers connected to the line. This choking coil should be practically non-

inductive to the generator currents and highly inductive to static disturbances. Fig. 196 shows one half of the Stanley choking coil, which has been specially designed to meet this requirement. The insulated

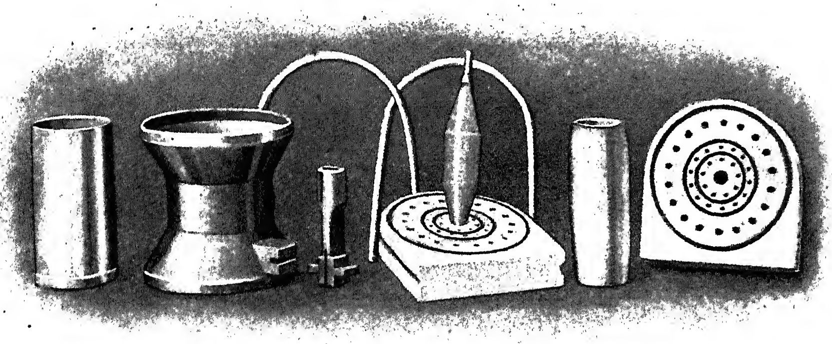


FIG. 194.—Unassembled parts of Stanley lightning arrestor.

cable forming the coil is passed through a hole in the centre of a marble slab. Half of this cable is wound in a coil as shown on one side of the marble slab, and the other half is wound in a similar coil on the back of

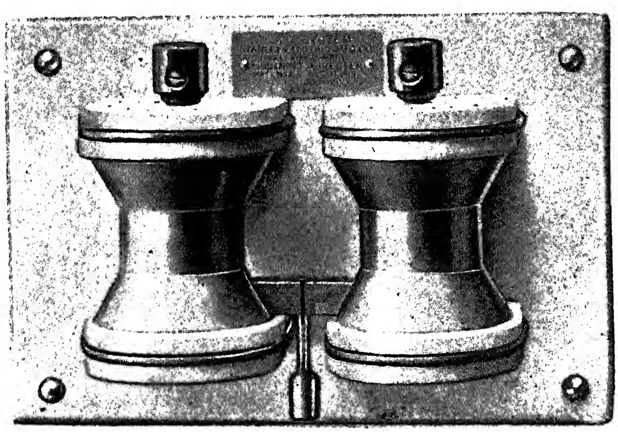


FIG. 195.—Complete pair of Stanley arrestor units.

the slab. The ordinary current from the generator during one half period enters the coil through the upper cable thimble, passes through the slab and round the turns of the coil on the back in a contra-clockwise

direction, then, returning through the hole in the centre, it passes round the coil on the face in a clockwise direction. It will be seen, therefore, that the field due to the coil on the front will be in an opposite direction to that due to the coil on the back, and the combined coils will in consequence be non-inductive. It has been found that the effective efficiency of these oppositely wound coils is very high for lightning discharges. This is attributed to the fact that with very high frequency discharges the phase of the current in the two parts of the coil is not the same at the same instant, and consequently, being wound in opposite directions, the currents

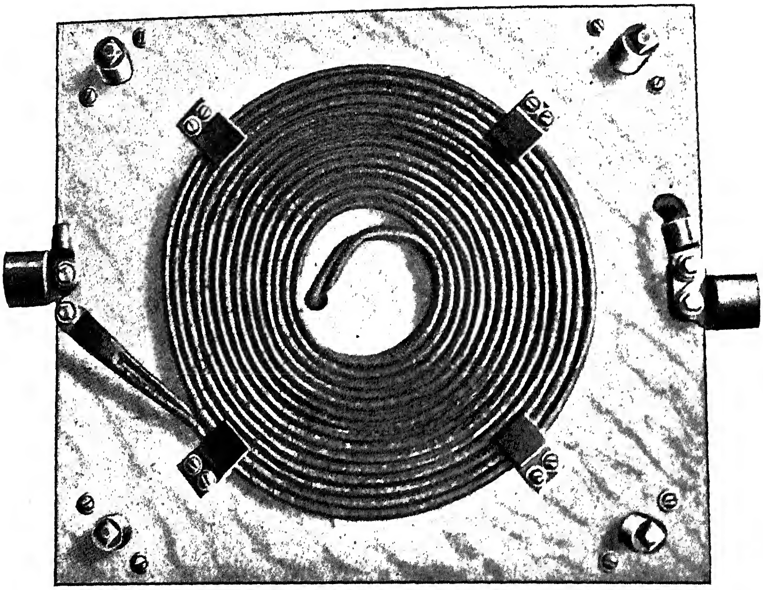


Fig. 196.—Choking coil for lightning arrestor equipment.

exercise a reinforcing magnetic effort instead of a mutually destructive one.

Fig. 197 shows a typical arrangement of arrestors and choking coils for a 15,000 volt three-phase transmission line. The rectangles represent arrestor units and the circles choking coils.

The Stanley Manufacturing Co.'s lightning arrestor for overhead direct current traction lines of 500 or 600 volts is an extremely simple device. It consists of a glass tube about 9 inches long, filled with oxidised metallic particles. The ohmic resistance of this tube is practically infinite (over 25 megohms). In consequence, 500 volts applied at the terminals will not force any appreciable current through it. A minute air gap is arranged in series with the tube as an extra precaution against grounding the line.

Whilst this arrangement prevents dynamic currents from passing, it is claimed that static discharges of extremely low potential flow readily to earth. Fig. 198 shows one of these arrestors arranged for protecting two 550-volt lines, the line wires being connected to the terminals on the left, and the terminal on the left being connected to earth.

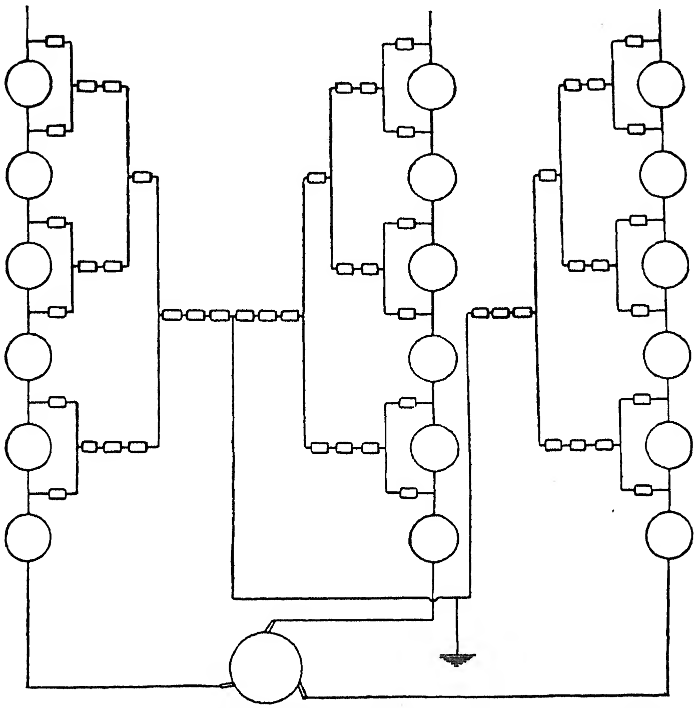


FIG. 197.—Arrangement of choking coils and arrestors for three-phase line.

To summarise, lightning arrestor equipments should fulfil the following requirements :—

(1) The air gap should consist of a large number of small gaps in series rather than of one comparatively large gap.

(2) The width and number of these gaps must not be so great as to require the potential of the lightning discharge to be higher than the potential necessary to rupture the insulation of the system.

(3) The width of the gaps must not be so small as to be constantly grounding the line potential through the arrestor.

(4) Precautions must be taken to prevent the gaps being short-circuited by moisture, dirt, or insects.

(5) Means must be provided to prevent the dynamo current following the lightning discharge and so establishing a permanent earth.

(6) Sufficient discharging surface must be provided to handle a heavy discharge without injury to the arrestor.

(7) Choking coils should be inserted in the circuit between the line and the generators or transformers.

Lightning arrestors are often supplemented by other devices to prevent breakdowns from atmospheric disturbances. Those members of the Institution of Electrical Engineers who joined in the Italian trip will remember that in connection with the Valtellina Electric Railway installation, in addition to the ordinary lightning equipment, a permanent high resistance leakage was established between each of the three-phase lines and earth. This leakage is maintained through vertical jets of water which are caused to impinge upon the lower side of umbrella-shaped screens hung from the live wires. This jet allows a constant leakage of one-tenth of an ampere. It is stated that, since this precaution has been taken,

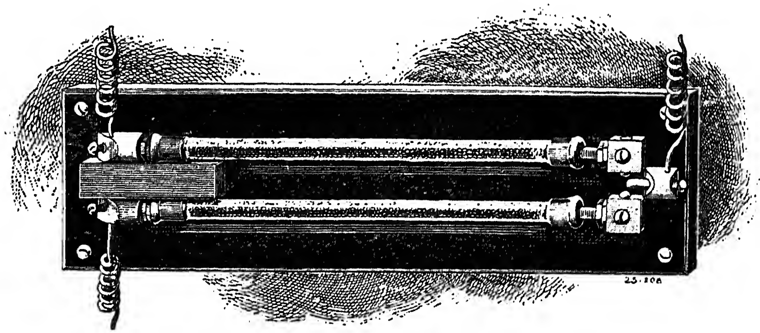


FIG. 198.—Stanley line discharger.

no sparking has been observed across the lightning arrestors at the generating station.

Another precaution that has been largely adopted in the United States is that of fixing a wire a few feet above the transmission lines, this wire being efficiently earthed about every hundred yards along the line. To appreciate the protection afforded by this grounded wire, it is necessary to briefly consider how atmospheric disturbances lead to static discharges from the transmission lines.

It is generally recognised that it is a most unusual occurrence for a line to be actually struck by lightning, and it is extremely doubtful whether it is possible by any known system of lightning protection to guard against heavy damage should a direct stroke occur. The static discharges that frequently do occur are, it is supposed, generally the result of electrostatic induction. If a cloud heavily charged with, say, positive electricity approaches the transmission lines, it will set free a positive charge on the latter that will tend to pass to earth, often breaking down

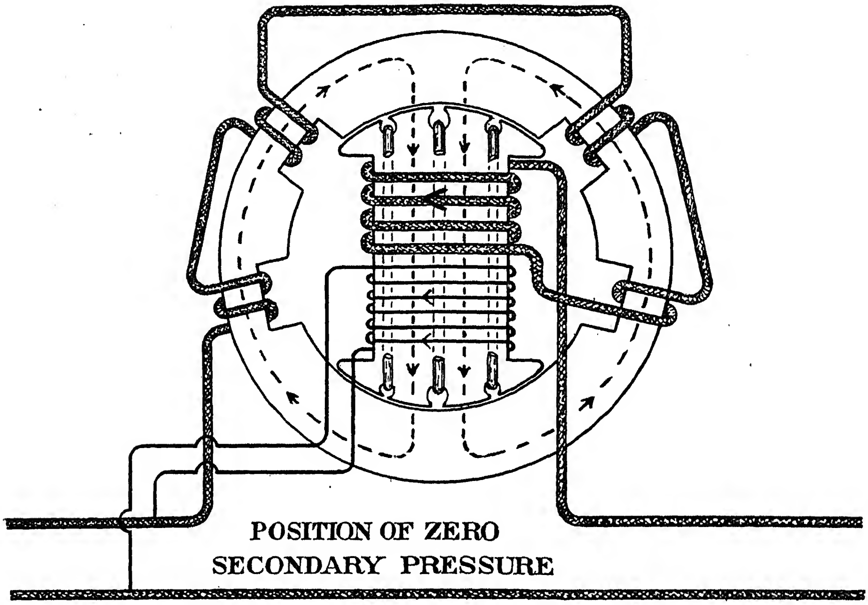
the insulation of the generators or transformers connected to the line in doing so. If now one or more other wires, earthed, at frequent intervals are run near the transmission lines, these will also be subjected to the inductive action of the charged cloud; but since these wires are efficiently earthed, the positive charge set free will pass to earth, the bound charge of opposite polarity remaining. The earthed wire becomes, therefore, negatively charged, and this negative charge will act inductively upon the adjacent transmission lines, tending to neutralise the inductive effect of the positively charged cloud. In many installations barbed wire has been used for this earthed wire, but so much trouble has been experienced through rusting, etc., that simple twisted or single wire is now recommended.

**Regulation of Pressure.**—When two or more transmission lines of different lengths are fed with an alternating current from one generating centre, it is sometimes necessary to boost up the pressure of the longest line to compensate for the greater drop. This is sometimes done by means of a boosting transformer, the secondary winding of which is connected in series with the line, and the primary across the two lines of opposite polarity. To vary the amount of boost, the ratio of the windings is altered, usually by cutting in or out turns in one of the windings. This entails the use of a multiple contact switch, and unless a large number of contacts are provided, the regulation is liable to be very jerky.

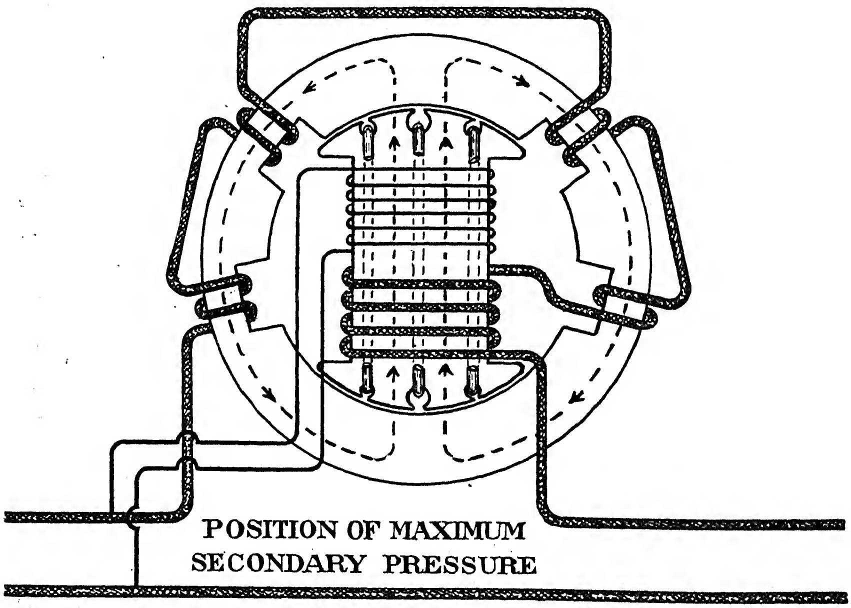
To overcome this difficulty Messrs Cowans have introduced a regulating transformer for which no switch is required, and that gives a perfectly gradual variation of boost. This is effected by mechanically altering the direction, in the secondary windings, of the flux due to the primary windings. In the early types of this device the primary coils were wound entirely on the moving core and the secondary on the stationary core; the magnetic leakage was, however, so heavy in this design that it had to be abandoned. In the present design, illustrated in figs. 199A and 199B, half of the secondary is wound on the moving core and half on the stationary core. In consequence, at least half of the secondary is practically unaffected by magnetic leakage.

When the moving core is in the position shown in fig. 199A, the magnetic lines induced by the primary cut the half of the secondary wound on the movable core in a positive sense, and the half of the secondary on the fixed core in a negative sense, and consequently the resultant secondary E.M.F. is nil. If, however, the movable core is rotated through an angle of 180 degrees, the magnetic lines cut both the secondary windings in a positive sense; the resultant E.M.F. is in consequence the sum of the two, and therefore a maximum.

A further improvement consists in fixing shading coils on the movable core, shown broken away in the diagrams where they cross the primary




A




B

FIGS. 199A and 199B.—Cowan-Still regulating transformer.

and secondary windings. These shading coils neutralise the induction of the secondary circuit when the movable core is in intermediate positions.

Lastly, the slots in the ring which contain the secondary coils are so placed that the area of gap between the movable core and the ring is as small and as equal as possible in all positions, thereby keeping the magnetising current as low and as constant as possible.

## Some Examples of Long Distance Transmission Schemes.

*Paderno Three-phase Transmission Scheme.*—An interesting example of the transmission of energy over a line about 20 miles in length by three-phase currents is the Paderno-Milan installation. This line has now been in successful operation for more than six years. At the time of its inception, this scheme was considered a somewhat daring experiment, but at the present time there are probably hundreds of similar or larger installations, all testifying to the success of the venture.

The generating station at Paderno is equipped with seven 1500 K.W. generators, coupled direct to seven turbines, which derive their power from the water of the Adda river, conducted through a canal over two miles in length. These generators are, as far as possible, kept running continuously; the load curve of this station is therefore practically a straight line. The current is generated without the intermission of transformers at the line pressure of 13,500 to 15,000 volts, and is transmitted at this pressure to a second combined steam generating station and distributing station at Porta Volta, on the outskirts of the city of Milan. Here it is transformed down from 12,600 volts to 3700. The supply is supplemented during the peak of the load by some of the 13,000 horse-power of steam generating plant at this station. During certain hours of the day the demand is smaller than the output of the water station alone; the steam plant is at this time entirely shut down, and the surplus energy from the water-power station is utilised for charging the batteries which are in turn used for supplementing the two generating stations during the peak load. The batteries used for this purpose are very large; they supply easily 3000 K.W. at the peak.

From the Porta Volta station a large portion of the current is distributed direct to a three-phase H.T. network arranged in the form of a ring round the outer portions of the city, and intersected by two cross branches. This network is fed by fifteen feeders connected to different points through fuses arranged in large pillars or kiosks, as shown in fig. 200.

In the upper half of each of these pillars a three-phase transformer is placed, for reducing the pressure from 3700 to 180 volts, at which it is distributed for lighting and power. There are no less than 153 of these pillars at present installed, having a total capacity of 11,600 K.W.

The switching arrangements at the Paderno station are excellent, and although this controlling gear was installed when the plant was first laid down, it is almost entirely in accordance with what is now considered the best modern practice. The instrument panels are arranged on a gallery at one side of the engine-room, the main oil break switches being fixed in a switch-room at the back of these panels and outside the main engine-room. The switches are operated through remote control mechanical gear by handles on the instrument panels. The generator switches are arranged, with suitable spacing, on one side of the switch-room, and the feeder switches on the opposite side, the H.T. 'bus bars and connections being in a basement below the switch-room floor. The lightning arrestor equipment is fixed in a room above the main switch-room, and the leading-in wires from the line are brought directly into this upper room through suitable leading-in tubes. The arrestor equipment consists of a large number of Wurtz spark gaps arranged with choking coils as described and illustrated in figs. 192 and 197.

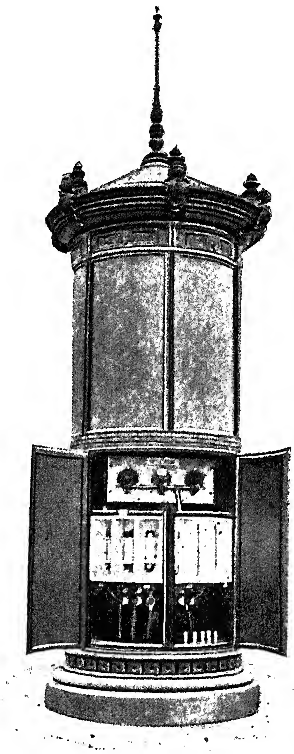


FIG. 200.—Transformer kiosk.

*Thury's Extra High-Tension Constant Current System.*—This system has many advantages which render it particularly suitable for some transmission schemes. The generators are constructed to give a constant current and a varying E.M.F. proportional to the load on the circuit. The higher voltages are obtained by coupling a number of generators in series.

One of the largest transmission schemes carried out on this system is that between St Maurice and Lausanne. For this scheme ten direct current generators are driven in pairs by five water-turbines. The nominal full load output of each generator is 150 amperes at 2230 volts. The whole of the generators may be coupled in series to give a line pressure of 22,000 volts. The chief disadvantage of the system is that the full working pressure must be carried by some of the generators and motors, as it is obviously not possible to use static transformers to increase and reduce the pressure, as in alternating current systems. This difficulty of insulating the machines

appears, however, to have been satisfactorily overcome by supporting the generators on porcelain insulators, and by using a flexible rubber coupling between the turbine and the generator. The frames of the machines are, therefore, not connected to earth.

One of the advantages claimed for the system is that the $C^2R$ losses in the circuit are constant, and in consequence maximum efficiency is obtained at full load. In cases where the power is supplied from a waterfall, and light load losses are of little importance, this is, of course, a valuable feature, as in such cases it is important that at the time when the generating plant is loaded to its utmost capacity the losses in transmission should be a minimum. It is equally obvious that for steam-driven plants with a poor load factor the system would be at a disadvantage, as the light load losses must be very considerable.

Another advantage claimed for the system is that the motors, being connected in series, may be fed by a single conductor, and in some cases this conductor may be arranged in a loop; thus several distributing centres may be fed by a single wire, whereas for any other system it would be necessary to run two wires to each distributing centre.

In one of the early installations the generators were at first separately excited, and were regulated by a solenoid fixed in series with the transmission line, the core of the solenoid operating the governor of the exciting turbine. This means of regulation failed, owing to the frequent breaking of the transmission line, which then caused the exciting current through the generators to be increased to such an extent that the whole of the generators were pulled up, and the elastic couplings broken. This difficulty was overcome by adopting series windings for the generators.

The controlling arrangements are much simpler than for any parallel system. Fig. 201 shows one method of regulating the apparatus in the generating station. It will be seen that the necessary switching devices are of the very simplest. The current is kept constant by a relay controlling device consisting of a solenoid and plunger attached to a commutator switch. So long as the current is normal, this commutator switch is held in the central position shown in the diagram. Should the current increase, the core of the relay will be pulled down, and the commutator switch will make connection with the lower contacts. This will cause the motor controlling all the sluice valves of the turbines to rotate in such a direction as to slightly close the valves, thereby causing the whole of the generators running at the time to reduce their output until the current is again normal, when the commutator switch will again return to its central position, and the motor will be stopped. If, on the other hand, the strength of the current falls below normal, the plunger will lift and cause the commutator switch

to make connection with the upper contacts, and the motor will slightly open all the sluice valves.

Although all the working turbines will normally be controlled simultaneously by the shaft driven by the controlling motor, arrangements are also made for independently varying the output of any generator. For this purpose the valve of the turbine to be independently varied is disconnected from the main controlling shaft, and the variation required is effected by the hand-wheel.

When the voltmeters across the working generators show these to be fully loaded, and a further increase of load is expected, all that is necessary,

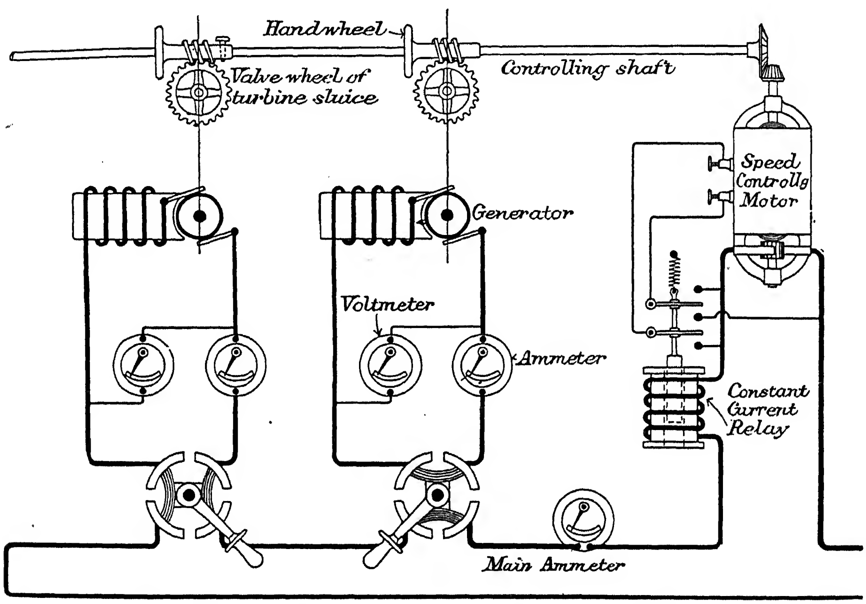



FIG. 201.—Generating controlling gear (Thury system).

to switch in another machine, is to run the incoming generator up to speed until the ammeter of this generator reads normal current on short circuit. The main switch is then turned through an angle of 90 degrees, thereby diverting the main circuit through the generator.

To cut a generator out of circuit the controlling sluice valve of its turbine is closed by hand, independently of the motor-controlled shaft, until the E.M.F. of the generator is reduced to zero. The switch is then replaced to the position in which the generator and line are respectively short-circuited. It will be clear that no current is interrupted by this switch under any conditions, and consequently there should be no sparking during switching operations.

The motors for use in connection with this system must be constructed

to give a counter electro-motive force proportional to the power absorbed by the motor, and as it is usually necessary that the speed of the motor should remain constant, the strength of the magnetic field or the position of the brushes must be altered for varying loads.

One of the following means is usually employed for the regulation of motors :—

(*a*) A secondary battery is connected as a shunt across the terminals of the motor.

(*b*) The strength of the magnetic field is varied.

(*c*) The angle of lead of the brushes is varied.

(*d*) A combination of the two latter methods is used.

For the first method the battery is connected up across the brushes. Should the load on the motor be reduced, its speed, and consequently its back E.M.F., tends to slightly increase; a portion of the current is therefore diverted through the battery, which becomes charged. If, on the other hand, the load is increased, the motor slows down, and the battery discharges through it. It will be seen, therefore, that the E.M.F. across the motor is practically constant. This method of regulation is only used for comparatively small motors, as the E.M.F. across the terminals is proportional to the output of the motor, and it would, therefore, be necessary to use a large number of cells if this system was employed for large motors.

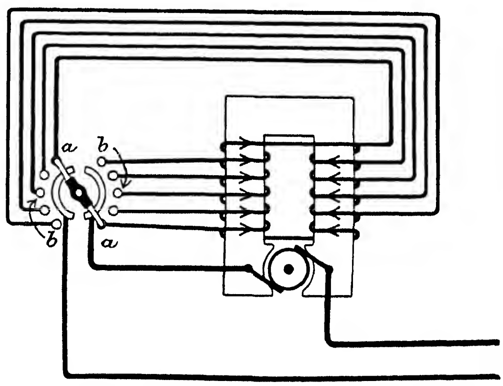


FIG. 202.—Thury series motor regulating switch.

Regulation by varying the strength of the field winding is effected by dividing the field into a number of sections, and altering the direction of the current in these sections to oppose or assist each other as required. This is accomplished in the manner indicated in Fig. 202.

When the switch is placed in the position shown at *a* the direction of the current in all the windings is such as to tend to magnetise the fields in one direction. When, however, the switch is changed to position *b*, the current through one half of the windings tends to magnetise the field in an opposite direction to the current in the other half. By turning the switch one more step forward, the field magnetism will commence to build up in the opposite direction, and the direction of rotation of the motor will consequently be reversed. This commutator switch may be automatically

controlled by means of a centrifugal governor constructed to strengthen the field by reducing the opposing turns in the event of an increase of load causing a reduction in the speed, or by increasing the opposing turns in the event of the speed of rotation being increased. This method of control is somewhat complicated by the large number of windings required to obtain a steady regulation, and it is in consequence little used, except for cases where it is desired to reverse the direction of rotation. The usual method of varying the strength of the field is to shunt the field windings by means of a variable resistance.

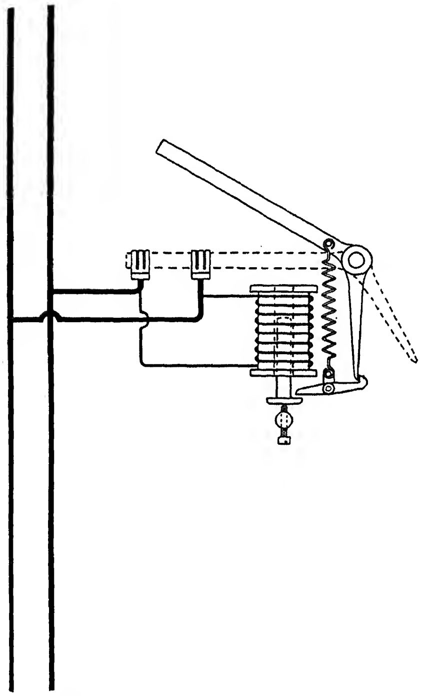


FIG. 203.—Excess potential cutout (Thury system).

For motors of a greater output than 50 or 60 horsepower it is generally necessary to alter the lead of the brushes simultaneously with the variation of the field. This is done by means of a small strap, the ends of which are fastened to the opposite points of the brush regulator. This strap passes over a small pulley on a shaft, which also carries the arm of a rheostat shunting the field winding of the motor. This shaft is rotated in one direction or the other by a double ratchet and pawl movement, which is in turn controlled by a centrifugal governor.

The type of switch used for controlling the motors is similar to that used for the generators. A modification is required, however, for starting large motors, as the self-induction of the windings of the motor is liable to cause considerable sparking at the switch when a large motor is connected in series with the main. To overcome this difficulty the switch is provided with an auxiliary device for breaking the arc.

It is obvious that no fuses or excess current cutouts are required in connection with this system, as it is impossible to obtain an excessive current under any conditions. It is, however, necessary to provide against abnormal rises of pressure due to an open circuit in any part of the system, and for this purpose short-circuiting cutouts constructed on the

principle illustrated in fig. 203 are used. One of these cutouts is connected in parallel with each motor, or across any loop of the system in which it is anticipated an open circuit may occur. Under normal conditions the current flowing through the solenoid will be insufficient to lift its core. If, however, an abnormal rise of pressure occurs, the core will be lifted, thereby releasing the catch, and allowing the switch to short-circuit the defective loop.

*Valtellina Electric Railway.*—Of the several power transmission schemes inspected by the Institution of Electrical Engineers during their trip to Northern Italy, the undertaking that excited greatest interest, probably on account of its novelty, was the electrification of that portion of the Italian State Railway between Lecco and Sondrio, and the branch line to Chiavenna, a total distance of 67 miles. This is the first practical application of the Ganz high-tension three-phase system to railway work. Power is transmitted from one generating station at a pressure of 20,000 volts, and transformed down to 3000 volts, at which pressure it is collected from the trolley wires and carried directly to the windings of the motors, without the intervention of transformers.

The power is obtained from turbines, driven by water from the river Adda, brought by a canal from a point three miles above the power station, which is situated at Morbegno, 15½ miles from Sondrio. This canal is 13 feet wide at the bottom, increasing in width to 14 feet 4 inches at the water level The average gradient is 1 per 1000. The water is conducted from the canal to the turbines through steel flumes 8½ feet in diameter. These run down the hillside at an angle of 45 degrees inclination to the horizontal. Packed gland expansion joints are provided near the upper end of the flumes, where the water pressure is light. The minimum water flow is stated to be 880 cubic feet per second, and as the available fall from the top level in the flume to the tail-race is 88 feet, the theoretical output of the fall is 9100 horse-power. It is estimated that over 7000 horse-power will be developed by the turbines from this water consumption. During the summer months, owing to the melting of the snow on the mountains, the water flow is considerably greater, while the summer railway traffic is at least twice as heavy as that to be served during the winter months.

Each flume serves two turbines, arranged with right and left-handed intakes. The speed of each turbine is controlled by a centrifugal governor which varies, by means of a relay, the angle of the guide blades, which are placed round the rotating blades carried by the main shaft. The relay consists of a cylinder provided with a piston which is thrust backwards and forwards by oil, at a pressure of about 140 lbs. per square inch, admitted to one or the other end of the cylinder by means of a slide valve controlled by the centrifugal governor referred to above. The pressure of

the oil is maintained by a pump on the end of the turbine shaft filling an ordinary hydraulic accumulator.

The three-phase alternators are separately excited by small generators on the end of each turbine shaft, the fields of these exciters being connected to a small auxiliary turbine-driven dynamo. A rheostat is inserted in series with each field, by which the E.M.F. of each generator may be regulated from the switchboard. As an additional safeguard, an emergency overnor inserts a resistance in the field of the exciter if the velocity of the turbine exceeds 170 revolutions per minute, the normal speed being 150 revolutions per minute.

The switchboard consists of marble panels upon which are mounted the low-tension measuring instruments and the operating handles of the high-tension switches. All high-tension apparatus and connections are carried on light iron frameworks in a spacious room at the back of the switchboard. A separate panel is provided for each generator, and there are two feeder panels. All high-tension switches are of the Schuckert horn break type; these switches are placed 20 feet above the floor level, and motion is communicated to them from the operating handles through an endless rope. There is only one three-phase feeder leaving the generating station, but this may be switched on to either set of 'bus bars through either of the two feeder panels referred to.

No attempt has been made to duplicate the feeders. Arrangements are, however, made for dividing the high-tension line into sections, thus permitting any portion to be cut out for repairs and the supply maintained through the 3000-volt lines.

The insulators used for supporting the high-tension feeders were all tested to withstand a pressure of 60,000 volts before erection. They are fixed on 8-inch iron brackets carried on the poles supporting the trolley wires. A distance of 2 feet is allowed between the three wires.

The diameter of the 20,000-volt wires is 8 mm. in the sections adjoining the generating station, and 7 mm. towards the outer ends. These primary feeders are not run through the tunnels, as it was feared that the damp atmosphere would be liable to affect the insulation.

Sub-stations are placed along the line at intervals of from five to seven miles. These sub-stations are divided into two parts. The incoming high-tension wires, and all high-tension connections, are located in the back room, whereas the single stationary three-phase transformer is placed in the front room. The horn break switches used for both the high-tension and low-tension sides are fixed in the upper portion of the building, and are operated by rope gear from below, as in the main generating station.

Overhead collection of the 3000 volt supply is made from two wires only, the third conductor of the three-phase system being the rails.

The collectors consist of two rollers mounted upon one axle pole 65

inches in length. This pole is constructed of hard wood saturated with oil under pressure. Each contact roller consists of a copper cylinder, about 3 inches in diameter by 2 feet long, mounted to revolve upon ball bearings. The two rollers are separated by a 9-inch length of insulating material.

The trolley arms are raised and lowered by compressed air. The valve controlling the air supply is so interlocked with the case containing the main switch that it is impossible for the drivers to open the latter without first lowering the trolley arm, and thus cutting off all supply.

Air for operating the Westinghouse air brake blocks, the rheostats, trollies, etc., is compressed by an electrically driven two-stage air compressor. For this purpose an 8 K.W. three-phase motor is supplied with current through a small static transformer carried on the car. The pressure of the air supply is automatically maintained at 100 lbs. per square inch.

One interesting feature in connection with the equipment of this installation is the coupling up of the motors in cascade.

It is well known that, if a standing three-phase motor having a short-circuited rotor is connected across the full line pressure, the motor acts more or less as a transformer having a short-circuited secondary winding, and in consequence it takes a very heavy current. This heavy current does not produce a correspondingly powerful torque, because the induced current in the rotor is practically in quadrature with the primary current in the stator. The torque may, however, be greatly increased, and the starting current reduced, by inserting a non-inductive resistance in series with the windings on the rotor.

In the Ganz cascade system, to obtain a big starting torque, the rotor windings of the primary motor are connected across the stator of a second motor, and a non-inductive variable resistance is connected in series with the rotor of this second motor.

The connections between the starting switch motors and controller are shown diagrammatically in fig. 204.

The high-tension three-phase currents collected from the rails and from the trolley lines are conducted respectively through the wheels of the car $A^1$, and through the trolley collectors $A^2$ $A^3$, the choking coils of the lightning arrestors $B^1$ $B^2$ and the fuses $C^1$ $C^2$, to the main high-tension switch D, and from this directly to the stator of the first motor E. The secondary currents induced in the rotor of this first motor are led to the stator of the second motor F through the lower connections of the controlling switch G. The rotor of this second motor is in turn connected through the upper section of the controller G to the variable non-inductive resistance H. This resistance consists of bundles of iron plates suspended in a vessel containing a solution of sodium carbonate; the height of this solution is controlled by the admission of air under pressure into the vessel through the valve I.

Now it is known that the torque of a three-phase motor reaches

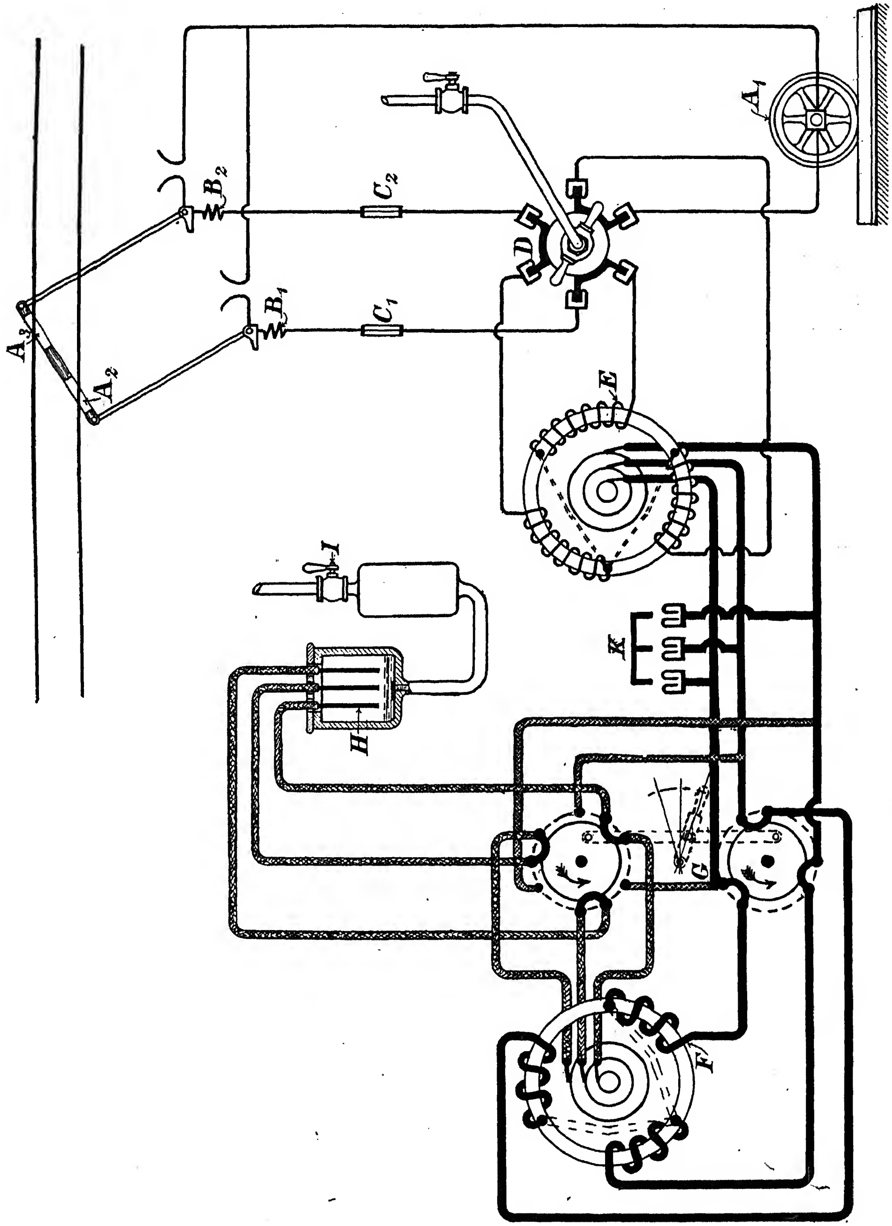



FIG. 204.—Cascade connection of motors (Ganz system).

a maximum at a definite speed for a given resistance in the rotor circuit. If, therefore, this resistance is constant, the motor will tend to

run at approximately this speed of maximum torque, whatever the load may be, so long as the periodicity of the supply remains constant. The speed corresponding to maximum torque may, however, be varied by increasing or decreasing the resistance in series with the rotor windings. If the resistance is entirely short-circuited, the torque will be a maximum when the motor is running almost synchronously. If two motors are coupled up in cascade, the speed at which maximum torque is reached in the second motor will, when its rotor is short-circuited, depend on the periodicity of the supply to its stator. This will vary with the difference in the velocity of the rotating field round the stator of the primary motor and the velocity of the rotor; in other words, the periodicity of the induced current will be directly proportional to the slip. It will be a maximum when the rotor of the primary motor is stationary, and a minimum when this motor is running synchronously. It is evident, therefore, that the combined torque of two motors connected in cascade will attain a maximum when the motors are running at a speed considerably lower than the maximum speed of the primary motor only. A little consideration will show that when the rotor of the second motor is short-circuited, the maximum torque exerted by the combination is reached when the rotor of the primary motor is rotating at approximately half the speed of the magnetic field of its stator. It must be remembered that the primary and secondary rotors are mechanically coupled together, and consequently the periodicity of one rotor must be the same as that of the other. It has also been shown above that the periodicity of the supply to the second stator is equal to the difference in the periodicity of the primary stator and its rotor, and when the secondary motor is running synchronously the periodicity of its rotor must obviously be the same as that of its stator. It follows, therefore, that the periodicity of the secondary rotor plus the periodicity of the primary rotor equals the periodicity of the primary stator; but since the periodicity of one rotor is equal to that of the other, each of them must be equal to half the periodicity of the primary stator, and both in consequence tend to run at half the speed of the field round the stator of the primary motor.

If, as may happen when the train is running down an incline, the rotors are driven above this speed of maximum torque, the combination will act as an ordinary synchronous motor driven above synchronous speed, and will in consequence generate current which will be returned to the line.

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